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Gravitational waves and the **BIG BANG** p. 36

September 2006

Astronomy®

Observing, telescopes, origin and fate of the cosmos

What powers dark energy?

Astronomy's greatest mystery deepens

What particle physics says about the universe p. 42

How you can view exploded stars p. 64

AND MORE!

See this month's solar eclipse p. 74

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The grandeur of galaxy M101 belies the fact that something scientists don't understand — dark energy — makes up all but a tiny fraction of the universe. p. 30

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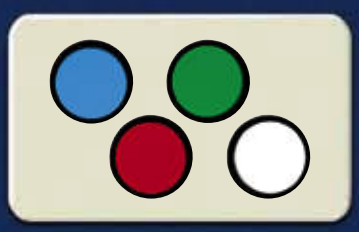

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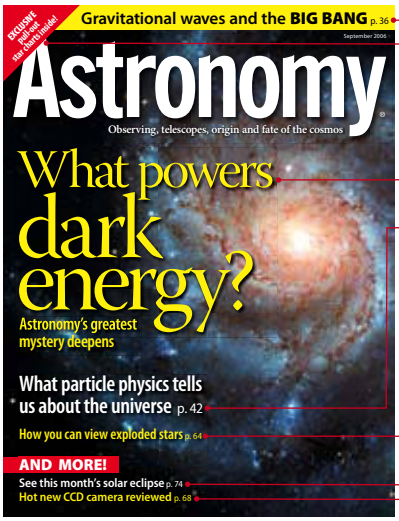
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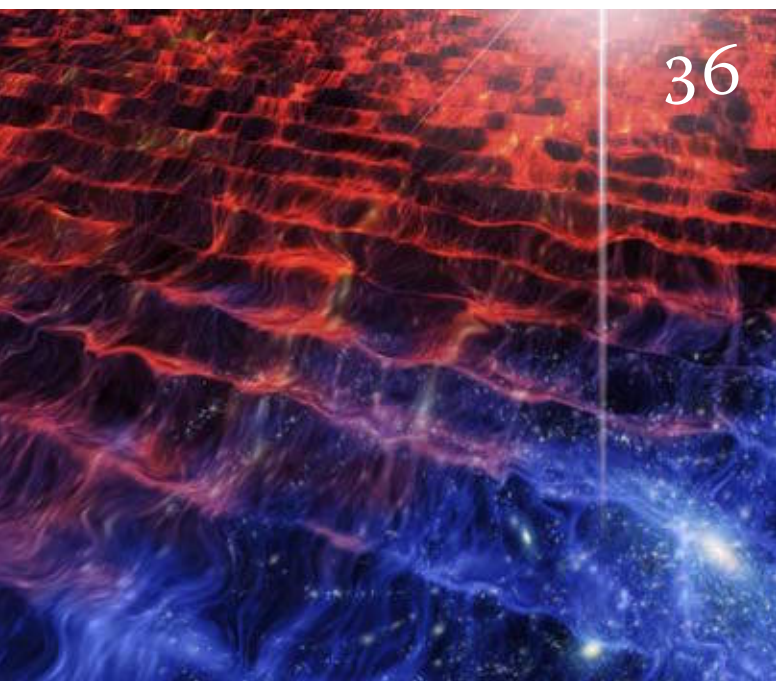

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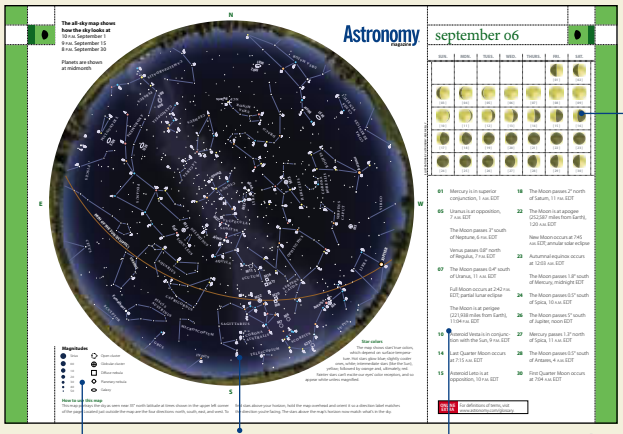

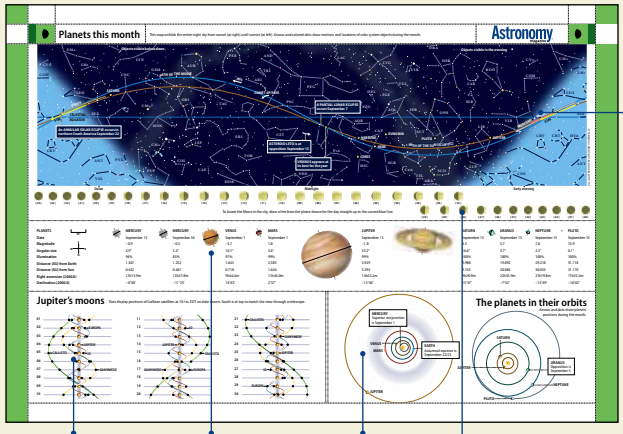

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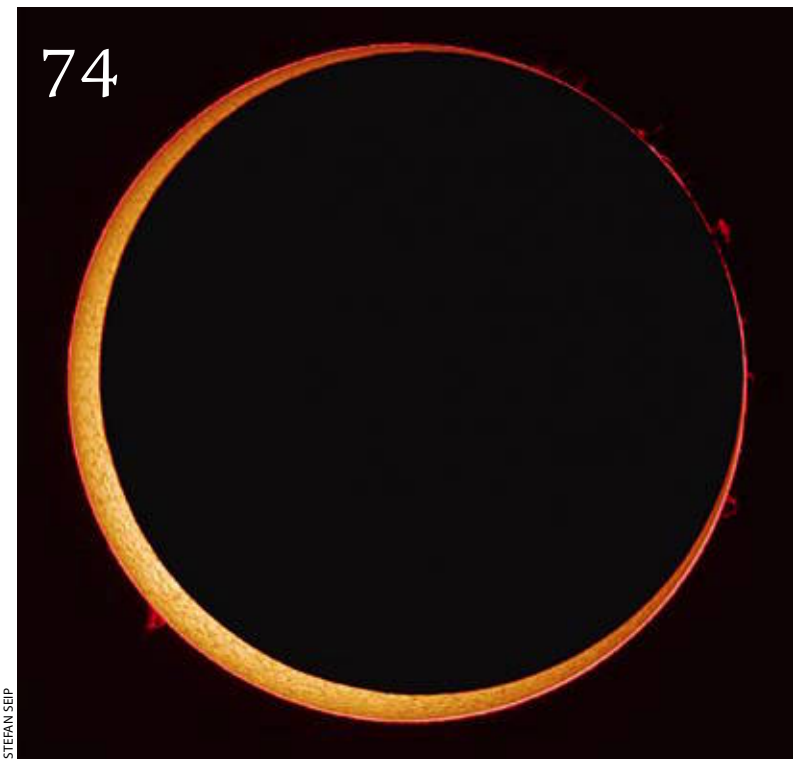

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BY DAVID J. EICHER

Let's talk stars

Astronomy is a field full of amazing

personalities. One of them is known to practically everyone who has taken a telescope outdoors and looked skyward: David H. Levy. A Tucson-based writer and lecturer, Levy has a history in amateur astronomy that extends back to the 1950s.

The discoverer or codiscoverer of more than 20 comets and author or coauthor of more than 20 books, he has done as much as anyone else to popularize amateur astronomy during the last 30 years.

One of Levy's myriad activities these days is producing a weekly Internet radio show along with his wife Wendee. "Let's Talk Stars," found at www.letstalkstars.com, is made available with help from Starizona, a telescope business owned by Dean Koenig. I'm proud to say *Astronomy* will now sponsor David and Wendee's show. You will find links to the show on Astronomy.com, and we hope you will frequently download and listen to programs from the extensive online archive.

The show lets David and Wendee talk with some of astronomy's most captivating, influential, and well-informed people. This year alone, the Levys have interviewed NASA astronaut Walter Cunningham; planetary scientist Richard Binzel of the Massachusetts Institute of Technology; Fred Espenak, NASA's "Mr. Eclipse"; star-cluster detective and USGS geodesist Brent Archinal; and University of Massachusetts physics professor and author Alan Hirshfeld. Past guests have included award-winning author Dava Sobel; telescope-maker John Dobson; planetary scientist Carolyn Shoemaker; Planetary Science Institute astronomer Bill Hartmann; and even your *Astronomy* editor.

Visit David's site to explore the wealth of knowledge and entertainment it holds. I think you'll come away with a greater appreciation of what's happening in amateur astronomy today.

ASTRONOMY: DAVID J. EICHER

WELL-KNOWN ASTRONOMER David Levy poses on *Astronomy*'s 2006 eclipse cruise.

Yours truly,

David J. Eicher
Editor

Astronomy

Volume 34, Number 9

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Stars carve rich tapestry

Astronomers have ringside seats to watch thousands of stars come to life in the Orion Nebula (M42), a dense cloud of gas and dust located just 1,500 light-years from Earth. The hottest, most massive stars have already emerged from their natal cocoons. Powerful stellar winds and ultraviolet light pour from these luminaries, shaping the intricate structures seen throughout the nebula. Meanwhile, untold numbers of fledgling stars still hide within thick gaseous pillars. This mosaic combines images taken by the Hubble Space Telescope during the course of 105 orbits with ground-based images from the European Southern Observatory's 2.2-meter telescope in Chile. The mosaic's apparent size nearly equals the Full Moon's.

NASA/ESA/M. ROBBERTO (STScI/ESA)/AND THE HST ORION PROJECT TEAM

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About Vixen

Vixen astronomical products have been treating their owners to the delight of the night sky since 1949. Always respected by quality minded amateurs, Vixen today offers some of the latest technology encased in the solidity of the past. Take the "goto" SPHINX mount and STAR BOOK; a sturdy German equatorial mount for all types of scopes combined with the first electronic star chart hand-controller. The SPHINX is just one example of Vixen's ingenuity on display at Certified Stocking Vixen Dealers and in stock for you to take home and enjoy tonight.

GP-D2 Equatorial Mount

Deluxe Equatorial Mount

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R200SS 8" f/4 Richfield Newtonian

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The Reviews are In: "A telescope mount for the 21st century"
***Astronomy* magazine, November 2005**

- "The Star Book is so easy to operate it flirts with user-interface perfection ... ."
- "As it stands now, the Sphinx is by far the easiest-to-use go-to mount."
- "Those interested in imaging should give this mount consideration."
- "The Sphinx is an extraordinary value because this amount of periodic error is normally encountered only in mounts 4 or 5 times its cost."
- "More good news: The mount is terrific."
- "To its credit, the screen worked well even at low temperatures — I subjected it to a test at -15° Fahrenheit (-26° Celsius) one night... ."

Recommended Accessories

Polar Axis Scope

Aluminum Case

Holds SPHINX, STAR BOOK, weights, battery case and more.

Tripod Carry Bag

Includes half-pillar pouch.

PORTA Alt-Az Mount

PORTA: Exceptionally Portable Mount!

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ED80Sf 80mm f/7.5 APO Refractor

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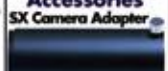
Recommended Accessories

SX Camera Adapter



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Targets not to miss

The search for thin lunar crescents on

either side of the Moon's conjunction with the Sun can be a fun and rewarding challenge for amateurs. Along with observing skill and planning, timing and sky conditions help ensure a successful sighting of the first and last visible hints of our Moon. ☾ Adding to the hunt's intrigue, within 24 hours of New Moon, staggered brightness peaks along the limb exhibit the lunar phenomena known as Saber's Beads. These slivers are reminiscent of the beautiful "string-of-pearls" effect seen at 2nd and 3rd contacts during a total solar eclipse. This similarity was first noted by veteran observer and Moon-hunter Stephen Saber. **— RICHARD CONE,** NANAIMO, BRITISH COLUMBIA

Let the dreamers dream

Today's scientists are not limited by tools or data, but by a shortage of imagination. Too many seem to spend most of their time amassing data and little time analyzing the data. Of course, spending one's life in a small room analyzing data and imagining possibilities is hardly glamorous or profitable. But look at what data and tools Albert Einstein and his contemporaries had when they established the basis for what we know of the universe today. I tend to think we should cut our imaginative thinkers (namely cosmologists) some slack! **— KEN STAUFFER,** CALGARY, ALBERTA

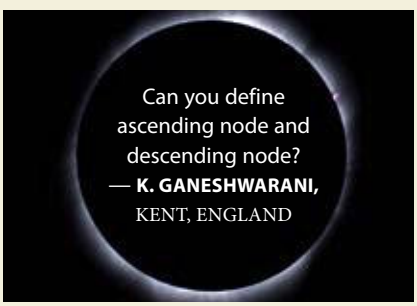
Space-station watch

Does anyone observe the International Space Station (ISS) anymore? I know it's not as major as Moon-watching, but it requires no equipment. I used it to spark a few people's interest during this year's Astronomy Day. When the space shuttle goes up for an ISS rendezvous, seeing both satellites is a thrill. **— "WEMBLEY,"** ASTRONOMY.COM FORUMS

Correction

In the diagrams on page 80 of the June 2006 issue, the words "begins" and "ends" are transposed related to satellite transits (left image) and shadow transits (right image). **— *ASTRONOMY* EDITORS**

We welcome your comments. Send letters to Astronomy *Letters, P. O. Box 1612, Waukesha, WI 53187; e-mail to letters@astronomy.com. Please include your name, city, state, and country. Letters may be edited for space and clarity.*



DAVID HARRINGTON

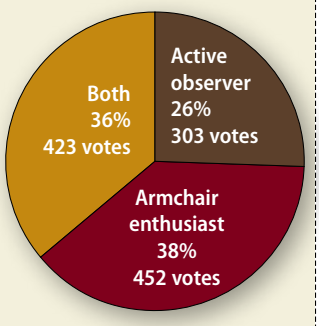
A SOLAR ECLIPSE occurs when the New or Full Moon reaches either its ascending or descending node. An annular solar eclipse occurs September 22 over the mid-Atlantic.

ASCENDING NODE vs. DESCENDING NODE

A celestial object's orbit intersects a fundamental plane at two points, called nodes. In the solar system, the fundamental plane astronomers use most is the ecliptic — the plane of Earth's orbit. The ascending node is the point where a celestial object crosses the ecliptic heading from south to north, while the descending node marks the point where it crosses the ecliptic heading north to south. In the Moon's case, a solar or lunar eclipse can occur only when a New or Full Moon, respectively, takes place near the time the Moon is at one of its nodes. **— RICHARD TALCOTT,** SENIOR EDITOR

Online poll results

POLL QUESTION:
Regarding your interest in astronomy, do you consider yourself an armchair enthusiast or an active observer?



Total votes: 1,178

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BY BOB BERMAN

See it to believe it

Of all the amazing astro-phenomena, a total solar eclipse arguably tops the list. Yet, most astronomy enthusiasts have never seen one. Maybe they just don't fully realize how wonderful it is. If you're in that group, I want to convince you, because the first step in the expensive process of meeting the Moon's shadow is deciding to do it.

Consider: Of the solar system's 150-odd moons, only ours is the perfect size and distance to neatly cover our Sun's disk. Sure, your telescope shows the shadows of Jupiter's moons sweep over the planet, but Io and his cousins block *too* much of the Sun. Jovians could never see a string of prominences.

Before Earth had life, our Moon was like Jupiter's moons — too nearby. The situation is now going the other way, and, in less than a billion years, it'll appear too small to cover the Sun. Only now are things just right, exactly when we excitement-hungry humans are here and psyched for it.

Life's great visual experiences make one want to whip out a camera, but, in this case, it's nearly futile. Among my March 2006 eclipse-viewing group huddled at the Libyan border, one Australian was an expert eclipse photographer. Yet, even his beautiful shots didn't capture what we saw.

Not even close.

And isn't that strange all by itself? You can take snapshots of plenty of things, and the photos resemble the subject being filmed. Not eclipses. Thanks to the eye's ability to see a vast range of brightness, the retina perceives both the brilliant purplish-red prominences shooting from the Sun's limb like nuclear geysers, and the delicate corona that spreads across the sky, ever fainter at increasing distances. Photos show one or the other, but not both.

Then there are the bizarre shadow bands, wiggling like snakes all over white surfaces just before and after totality. They cannot be photographed. The pictures and videos come out blank!

So I counseled the group beforehand: Let the experts take the pictures. Fill these precious few minutes absorbing the indescribable experience. And spend half the time with binoculars — with filters, of course! Simple.

Just before totality, the Sun's light looked strange on the countryside. Shadows became stark, and the light became warmly colored, with contrasts weirdly accentuated. You *knew* something alien was afoot.

IT'S LIKE PLAYING
Handel's "Hallelujah Chorus" on an elevator.

Animals respond accordingly, and so do people. Many weep. Some make visceral groans and exclamations. No, it's nothing like the photographs, and as for TV — that shouldn't even be allowed. It's like playing Handel's "Hallelujah Chorus" on an elevator.

Superimposed on all of this are the circumstances of where you happen to be. As a longtime eclipse lecturer, I do my talks in the days ahead of the event. I shut up during the eclipse. In 1999, during an *Astronomy* magazine eclipse cruise in the Black Sea, I perched alone in a crow's nest with a long microphone cable and made my final announcement: "Totality starts in 10 minutes, see you later" — and then turned off the loudspeakers. Does this experience require narration? Personally, I like totality served raw with just the natural sounds of the wind and freaked-out animals.

That time, another cruise ship had dropped anchor not far from ours, and although we thankfully couldn't make out the words, we could hear *that* eclipse astronomer blabbing through the ship's loudspeakers through the whole thing. Toss him overboard.

This year's eclipse, at the Egypt-Libya border, was unique. The Egyptian government had thoughtfully set up a tent city for scientists and visitors, and Arabic pop music blared through loudspeakers. It was EclipseStock 2006. Morning fog lent an additional surreal touch (there was even a fogbow!), and so did a grandstand set up for the imminent arrival of the President of the Arab Republic of Egypt Hosny Mubarak and his wife — along with enough security personnel to protect an entire planet. I was able to sneak my group of 43 away from that busy scene to a couple of miles down the highway, where we fanned out in the desert. You can always find your own space if you wish.

My first totality was in 1970 at Virginia Beach, where the happy crowds were just as excited but more spread out.

It's not too early to plan ahead. We can drool about the upcoming United States eclipse, a 100-mile-wide coast-to-coast swath 11 years from now, and watch totality from Nashville or the Tetons. But who can wait? Some are already arranging their latest mortgage to finance the next totality, an inconvenient 2.5-minute affair August 1, 2008, in central Russia, Mongolia, and western China. Or the big one, the century's longest, at 6.5 minutes July 22, 2009, with a track through India (including the spiritual Disneyland of Varanasi), China, and a Japanese island. Summer vacation time. We'll look at statistical weather prospects, then decide where to go. Are you in?

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This course is crafted to make the key concepts and triumphs of calculus accessible to nonmathematicians. It is not designed as a college calculus course; rather, it will help you see calculus around you in the everyday world.

Every step is in English rather than "mathese." Formulas are important, certainly, but the course takes the approach

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About Your Professor

Professor Michael Starbird is a distinguished and highly popular teacher with an uncommon talent for making the wonders of mathematics clear to no-mathematicians. He is Professor of Mathematics and a Distinguished Teaching Professor at The University of Texas at Austin, where he has received the President's Associates Teaching Award, the Jean Holloway Award for Teaching Excellence, and the Friar Society Centennial Teaching Fellowship.

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BY GLENN CHAPLE

All aboard Chaple's Arc

"I'd love to know that something up there had my name on it," I lamented to a group of my astronomy friends. Scattered across the heavens, you'll find lunar and planetary craters, minor planets and comets, stars and deep-space objects bearing the names of men and women

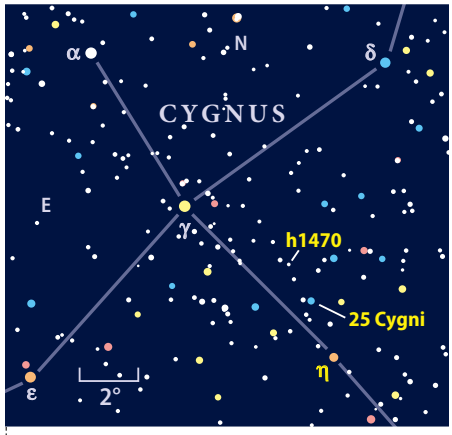
with astronomical connections — a "Who's Who" of astronomy. To merit the International Astronomical Union (IAU) naming a piece of cosmic real estate in your honor, you either have to discover a space object or make a significant contribution to the field of astronomy.

"But there is a sky object named for you," one friend noted.

"Really? Which one?" I replied.

"The Dumbbell Nebula!" he retorted to a chorus of laughter.

"Ha, ha, ha. Very funny!" What my unsympathetic friends don't realize is a piece of cosmic real estate does have my name on it — even though the IAU doesn't sanction it. It's called "Chaple's Arc."



STAR-HOP your way to Chaple's Arc: Eta Cygni to 25 Cygni to h1470.
ASTRONOMY: ROEN KELLY

Climb on two-by-two

In my early years as an amateur astronomer, I was a double-star fanatic. After being smitten by a view of the showpiece pair Mizar (Zeta [ζ] Ursae Majoris), I set out on a crusade to observe every double star within the reach of my 3-inch reflecting telescope. I began my constellation-by-constellation hunt for stellar pairs guided by *Norton's Star Atlas* and *Webb's Celestial Objects for Common Telescopes* — which, despite being written in the late 1800s, has useful lists of double stars.

During late summer 1972, I was working on a list of targets in Cygnus. One of my targets was **h1470** — number 1,470 out of more than 5,500 double stars cataloged by John Herschel during the early decades of the 19th century. Webb commented on the primary star's ruddy color and explained how a spacious 29" (arcseconds) separate the magnitudes 7 and 9 component stars. Using **Eta (η) Cygni** as a starting point, I star-hopped 2° north and slightly east to **25 Cygni**. Continuing another degree brought me to h1470. I marveled at what I saw through the eyepiece. So many stars looked double, I thought my scope's mirror might have cracked. After realizing my scope was fine, I gazed in astonishment at four double stars arranged in a ½° arc. I wrote in my logbook:

"h1470 proved difficult to find, because I could see four doubles in the field — quite a surprise, but perplexing."

Four summers passed before I returned to the area. This time, I was a more experienced observer, able to single out h1470. I could also make reasonable estimates of the magnitudes and separations of the remaining three doubles. Each sports a primary star of 7th or 8th magnitude, whose 9th-magnitude companion is 30" to 45" away.

I described this fascinating group in a "Double Stars of the Month" column in the September 1980 issue of *Deep Sky Monthly* (whose cover showed a photo of the Dumbbell Nebula). After reading the article, amateur astronomer John Pazmino viewed the h1470 group from New York's light-polluted skies and wrote the following piece in the October 1980 *Eyepiece* — the newsletter of the Amateur Astronomers Association.

"Back in Brooklyn, I found Chaple's Arc with my Dynamax-8 and lo: it's a startling sight! There, around an arc about ½° in diameter are four beautiful double stars! From Manhattan I examined the group through my Questar, and even though the air was somewhat soupy, the arc stood out plainly even under both 40 and 80 power.

"Urbanites will delight over this array. The four main members are all bright and widely separated. With Cygnus with us through the end of the year, Chaple's Arc will offer yet a few more months of fascinating viewing."

Why, you may well ask, should the tale of Chaple's Arc appear in a column for beginners? Simple. You'll have to star-hop to find the Arc, and that's a skill the novice telescopist needs to learn. Its location in a rich Milky Way field adds a dimension of difficulty to the hop.

Recently, I visited h1470 — this time with a 13-inch Dob. A clutter of faint background stars detracted from the visual impact of the Arc. A quick check with my faithful little 3-inch reflector confirmed my suspicion that Chaple's Arc is most impressive when viewed with a small-aperture scope (or a large scope in a light-polluted area). Check it out, and let me know what you think.

Next month: We'll explore another space object named after me. Clear skies!

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BY PHIL HARRINGTON

Target the arrow

In his poem, "The Arrow and The Song," Henry Wadsworth Longfellow (1807–1882) wrote: "I shot an arrow into the air, it fell to earth, I knew not where." This might have been true for him, but we need to look no farther than the tiny summer constellation of

Sagitta to find an arrow shot by Heracles (in Roman mythology, Hercules).

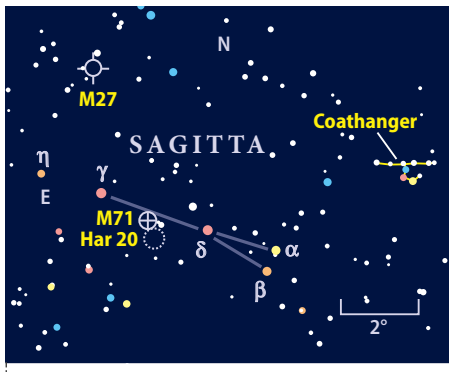
According to one legend, Heracles shot the arrow at Aquila the Eagle, whom Zeus had sent to attack Prometheus for stealing fire from the gods. Other legends tell how Sagittarius, Centaurus, and even Cupid shot at Sagitta.

Sagitta gets its shape from five faint stars that lie about a third of the way from Altair to Deneb along the eastern side of the Summer Triangle. The small constellation may just squeeze into your binoculars' field of view, giving you a great chance to compare the stars' brightnesses and colors.

Two of the stars along the arrow's shaft, labeled Delta (δ) and Gamma (γ) Sagittae, are red giants, while Eta (η) Sagittae — at the arrow's eastern tip — is an orange giant. The two tail-feather stars, Alpha (α) and Beta (β) Sagittae, are yellow giants. Soften your binoculars' focus just a bit to enhance the stars' subtle colors.

The arrow also contains a pair of challenging star clusters near 9 Sagittae, a dim star midway between Delta and Gamma. The first, **M71** (NGC 6878), is found just to the star's east-northeast. Look for the cluster's dim splotch of grayish light against a starry backdrop.

For years, M71 remained a mystery: Was it a densely packed open cluster, like the Wild Duck Cluster (M11) in Scutum (discussed in this column in the September 2005 issue, "Open a star window"), or was M71 a loosely packed globular cluster? Early analyses were inconclusive, but recent studies using improved techniques prove



SAGITTA OFFERS challenges for beginning and advanced binocular observers. This finder chart will help you target some of the objects lurking around the arrow.
ASTRONOMY: ROEN KELLY

M71's status as a globular cluster, albeit an unusual one.

Can you spot a second, fainter blur of light just to the south of 9 Sagittae? If so, you've seen an open star cluster that neither Charles Messier (1730–1817) nor William Herschel (1738–1822) ever saw. Today, we know it as **Harvard 20**. Although some 15 to 20 stars call this cluster home, their combined light equals only 8th magnitude, which can make the cluster tricky to spot through binoculars.

Okay, those two targets may be a little daunting, but you should have no trouble with the next. In fact, it can even be seen faintly by the naked eye under dark skies. The **Coathanger** asterism lies just across the border in the constellation Vulpecula and looks amazingly like its namesake through binoculars. To find it, aim toward the arrow's tail feathers, and then look about a binocular field to the northwest (up and to the right).

The shape amazes new stargazers, although, from the Northern Hemisphere, the Coathanger hangs upside down. Six stars aligned in a straight line form its crossbar, while four other points of light curve away to create the hook. The Coathanger is one of my favorite binocular targets in the late summer sky, even if it isn't a bona fide star cluster. Data gathered by the European Space Agency's Hipparchos satellite a decade ago prove the stars align by chance, with each lying anywhere from 220 to 1,100 light-years away.

Our last target this month also resides in Vulpecula, but it is most easily found by starting at Eta Sagittae, which marks the arrowhead. Wind your way northward along a zigzagging line of half a dozen faint stars that lead to a tiny blur of dim light. This is M27 (NGC 6853), the famous **Dumbbell Nebula**. Its shape appears rectangular through 7x and 10x binoculars, while higher magnifications hint at its characteristic hourglass profile. The first planetary nebula ever found, M27 is the still-expanding shell of gas a star expelled 3,000 to 4,000 years ago.

When Heracles shot Sagitta into the air, he may have missed Aquila, but he struck gold for binocular observers. The next chance you get, pay Sagitta a visit and enjoy its unique sights. But first, be sure to stop by Astronomy.com this month for some other noteworthy objects that lie in and around the area.

Next month, we'll shoot straight from Sagitta to a pair of autumn globular clusters. Till then, remember two eyes are better than one!

ONLINE EXTRA To find a list of more binocular-friendly targets in Sagitta, visit www.astronomy.com/toc.

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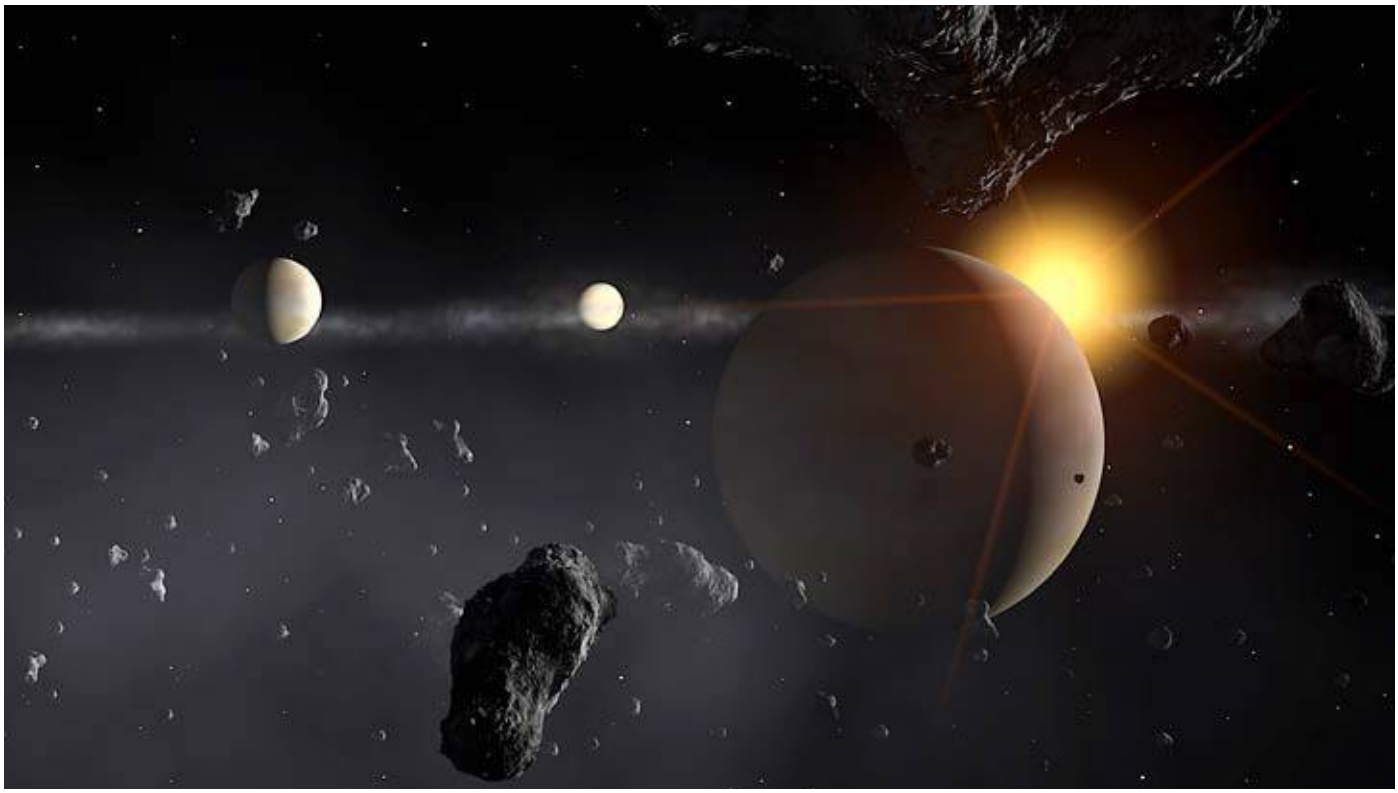

ESO

HAT TRICK. Three newly discovered Neptune-mass planets bracket a possible asteroid belt around the star HD 69830 in this European Southern Observatory illustration. NASA's Spitzer Space Telescope last year found evidence the star may possess a large asteroid belt.

24 Hubble images Red Spot, Jr.

26 Formation-flying satellites test in ISS

27 Comet breakup sends X rays flying

29 Akari sees first light

Three "Neptunes" orbit a Sun-like star

Swiss astronomers have detected three Neptune-mass planets around a star that may also host a super-size asteroid belt. The newfound planets have minimum masses between 10 and 18 times that of Earth; the planets Uranus and Neptune contain 14.5 and 17.1 times Earth's mass, respectively.

The team studied the Sun-like star HD 69830, located 42 light-years away in the constellation Puppis, for more than 2 years. The orbiting planets give the star a slight wobble, which the astronomers detected. Three roughly equal-mass planets take 8.67, 31.6, and 197 days, respectively, to circle the star. All three planets lie closer to their star than Venus does from our Sun.

The outermost world is the lowest-mass planet known to reside in a star's so-called habitable zone. This is the region around a star where liquid water can exist at the surface of rocky or icy bodies. The possible presence of an asteroid belt there, discovered in April 2005 with NASA's Spitzer Space Telescope, adds "cherry to the cake," says team member Willy Benz from Bern University.

"This is hot stuff," comments Alan Boss, an astrophysicist at the Carnegie Institution of Washington. Boss says he's "willing to bet" planets like these represent the massive end of an earthlike exoplanet class.

The team reports its results in the May 18 issue of *Nature*.

— FRANCIS REDDY

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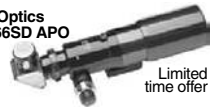

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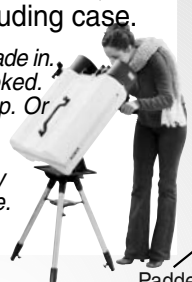

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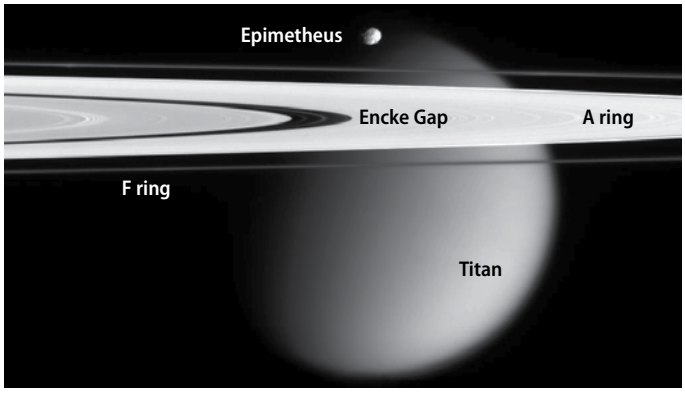


NASA/JPL/SSI

MOONS AND RINGS. Cassini views Titan, Epimetheus, and the rings.

Saturn moons, large and small

NASA's Cassini mission sees rings and moons in ever-changing combinations. The spacecraft snapped this portrait April 28, 2006, when it was about 415,000 miles (667,000 kilometers) from Epimetheus and 1.1 million miles (1.8 million km) from Titan.

Titan, the solar system's second-largest satellite at 3,200 miles (5,150 km) across, forms the backdrop. Tiny Epimetheus, just 72 miles (116 km) wide, is one of Saturn's co-orbital moons; it periodically swaps orbits with Janus, not shown.

Cassini views Saturn's narrow F ring and bright A ring nearly edge-on. The prominent dark band is the Encke Gap, which is 200 miles (325 km) wide. — **F. R.**

SOHO will continue mission

STAR PERFORMER. **SOHO's instruments will be on the lookout for solar flares and coronal mass ejections through 2009.** NASA/ESA/SOHO

The Solar and Heliospheric Observatory (SOHO), which scientists once hoped would last 2 years, celebrated its 10th anniversary in space last December. During this time, SOHO has exceeded all expectations, so NASA and the European Space Agency will continue operations through 2009.

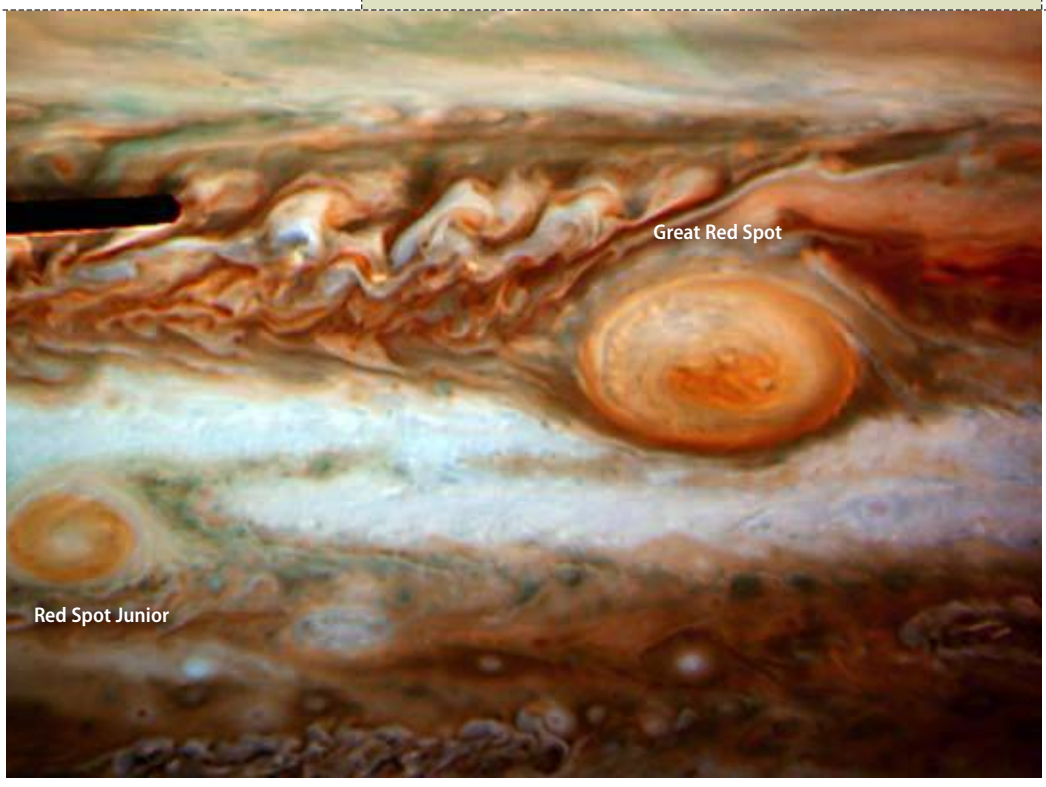
"This mission extension will allow SOHO to cement its position as the most important spacecraft in the history of solar physics," says Bernhard Fleck, SOHO's project scientist. "There is a lot of valuable work for this spacecraft still to do." SOHO will now collaborate with NASA's twin STEREO satellites and the Japanese Space Agency's Solar-B, all of which are scheduled to launch later this year.

— **JEREMY MCGOVERN**

Hubble images Red Spot, Jr.

Astronomers using NASA's Hubble Space Telescope (HST) imaged a new companion to Jupiter's Great Red Spot April 25. The feature, nicknamed Red Spot, Jr., is about half the size of its relative.

Scientists have tracked the storm since 2000, when it appeared as a white oval designated BA. Last November, Oval BA began turning brown, and, by March 2006, its tint matched the Great Red Spot's. Astronomers suggest the color shift happened because the storm strengthened, lofting material as high in the atmosphere as the Great Red Spot does. — **LAURA LAYTON**

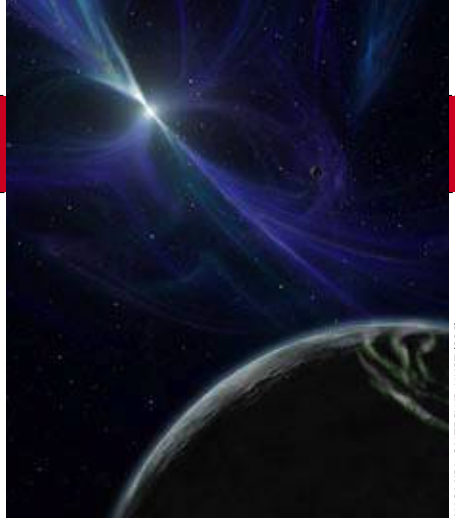


NASA/ESA/I. DE PATER AND M. WONG (UC BERKELEY)

RED JUNIOR. Hubble captured this portrait of Jupiter's Great Red Spot and Red Spot Junior April 25.

Pluto's moons

The International Astronomical Union has approved the discovery team's names for S/2005 P1 and S/2005 P2: Hydra and Nix, respectively.



NASA/JPL-CALTECH/R. HURT (SSC)

PHOENIX WORLDS. **Planets may pop out of a supernova blast's wake.**

Expect more pulsar planets

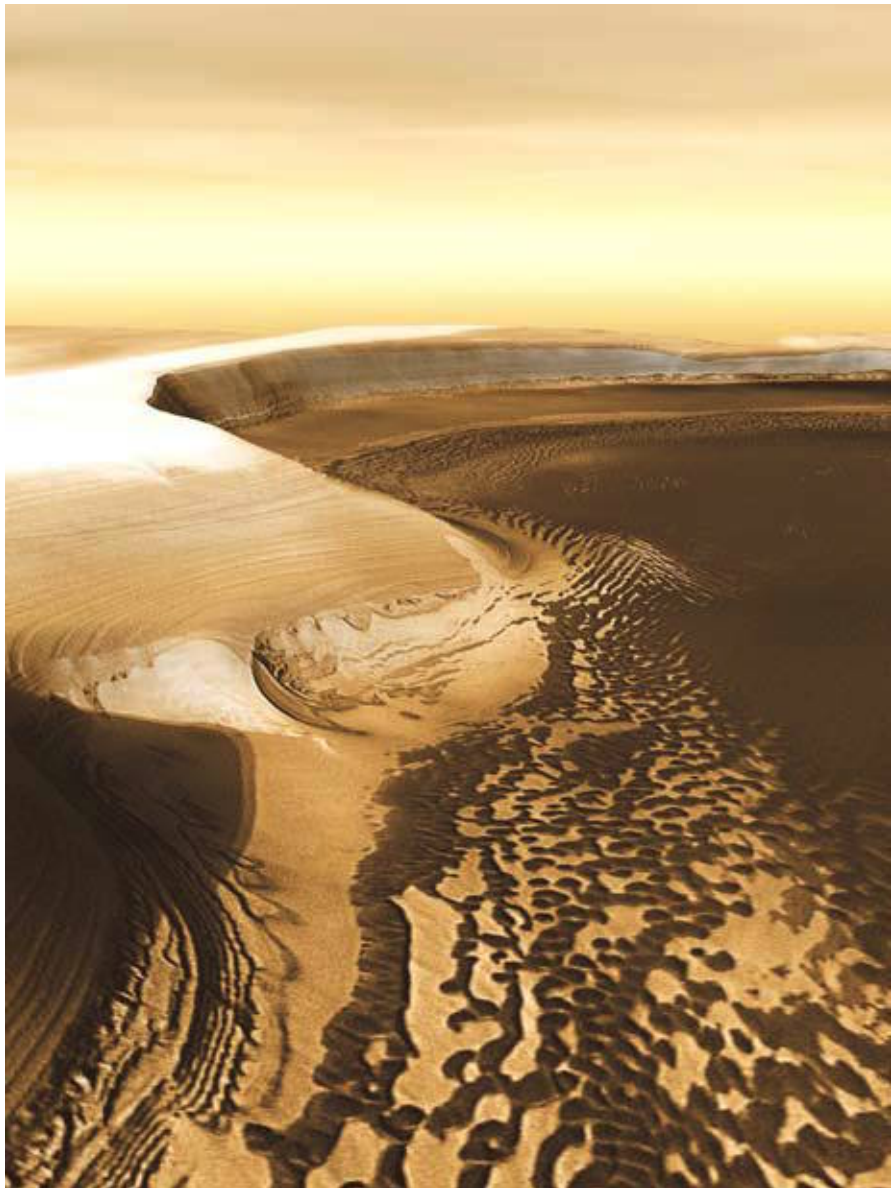
NASA's Spitzer Space Telescope has spied planet-forming ingredients in a disk around pulsar 4U 0142+61, which lies 13,000 light-years away in Cassiopeia. Scientists now speculate that pulsar planets — worlds formed from debris surrounding a pulsar — may be more common than previously thought.

"I find it very exciting to see direct evidence that the debris around a pulsar is capable of forming itself into a disk," says Aleksander Wolszczan of Pennsylvania State University. In 1992, he and Dale Frail of the National Radio Astronomy Observatory discovered planets orbiting pulsar B1257+12. Astronomers think the planets formed after a supernova created the fast-spinning, radio-wave-emitting pulsar.

"We're amazed that the planet-formation process seems to be so universal," says Deepto Chakrabarty of the Massachusetts Institute of Technology in Cambridge. He led the team that uncovered the debris disk around 4U 0142+61.

If the star that formed the pulsar ever had planets, they were likely obliterated when the star blew up about 100,000 years ago. But dust particles formed in a supernova's expanding shell can fall back toward the pulsar. This creates a disk of debris that may form new planets.

"This might be the beginning of a second generation of planets," says Wolszczan. The team's results appear in the April 6 issue of *Nature*. — **L. L.**



NASA/JPL/ARIZONA STATE UNIVERSITY, R. LUK

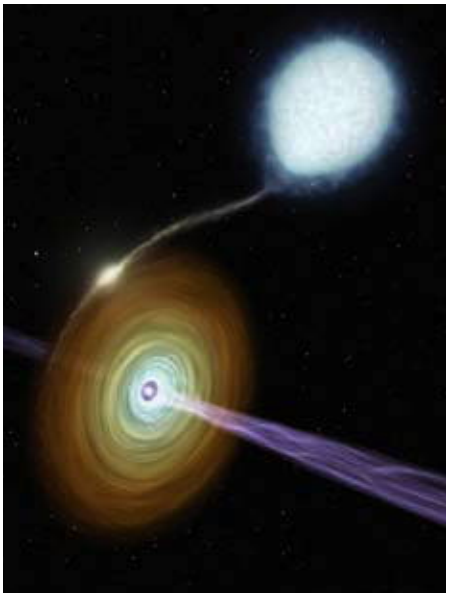
SNAPSHOT. **Season by season, year by year, alternating cycles of ice and dust deposits built up the layered walls of Chasma Boreale, near the martian north pole.**

Chasma Boreale vista

The Red Planet hosts some of the solar system's most dramatic terrain, including the largest-known volcano (Olympus Mons) and an enormous rift that would span the continental United States (Valles Marineris). Less well known is an ice-bordered depression in Mars' north polar cap named Chasma Boreale.

As this 350-mile-long (570 kilometers) trough arcs into the ice cap, the valley's width narrows from 75 miles (120 km) to 22 miles (35 km). Where it ends, cliffs of layered rock tower 4,600 feet (1,400 meters) above the valley floor. Winds blowing off the ice sculpt sand dunes in the canyon floor.

To produce this perspective of Chasma Boreale's northern tip, scientists draped images from NASA's Mars Odyssey spacecraft over a terrain model. The view exaggerates elevations by 2.5 times. — **F. R.**



ESO

JUNIOR JETS. **Neutron stars shoot narrow jets (purple in this illustration) just like black holes, say astronomers.**

Spitzer finds neutron-star jets

Astrophysicists using NASA's Spitzer Space Telescope spotted fire-hose-like jets of matter spewing from a neutron star in a close binary system. Continuous narrow jets are a hallmark of accreting black holes, and this is the first time such jets have been observed coming from a neutron star.

"Our data show that the presence of an accretion disk and an intense gravitational field may be all we need to form and fuel a compact jet," says Simone Migliari, an astrophysicist at the University of California, San Diego's Center for Astrophysics and Space Sciences. He's the lead author of a paper on the system published in the May 20 *Astrophysical Journal Letters*.

The neutron star lies in the X-ray binary 4U 0614+091, which is some 10,000 light-years away in Orion. The neutron star is more than 14 times the mass of the normal star orbiting it. Some of the material leaving the normal star is captured into an accretion disk around the neutron star. Matter nearest the neutron star may spiral out along the star's spin axis, creating faint jets. — **L. L.**

Formation-flying satellites test in ISS

NASA

NEXT STOP, ISS. **SPHERES hardware, tended by engineers, floats freely during tests aboard NASA's KC-135.**

The first of what is supposed to grow into a small fleet of free-flying test satellites arrived aboard the International Space Station (ISS) in April. Missions later this year are scheduled to deliver two more. Called SPHERES, for Synchronized Position, Hold, Engage, Reorient Experimental Satellites, the volleyball-size objects are designed to fly in precise formation. The first tests will use small wall-mounted beacons to supply a positional landmark, but, eventually, each SPHERES will use the others for reference.

Each satellite is about 8 inches (20 centimeters) wide, weighs about 7 pounds (3.2 kilograms), and has its own internal avionics, software, and communications systems. Each SPHERES free-flier uses 12 carbon-dioxide-gas thrusters to maneuver through ISS' Destiny Lab. When the units are operating, their bursts of CO_2 stress ISS' air-processing system about as much as an additional crew member's respiration would. These internal free-fliers use two AA batteries for power. They find distances using ultrasound; later, external versions will need radio beacons or lasers.

Free-flying satellites date back to the astronaut-carrying Manned Maneuvering Unit (MMU) of the 1980s and its predecessor on Skylab. But the SPHERES concept is original and astronomy-related. The program's goal is to demonstrate control methods for a distributed network of small objects. Perhaps someday, similar satellites could carry mirrors as components of a space telescope that spans tens of kilometers. Delivered to a distant Lagrange point, where gravitational gradients are weakest, such a telescope could become an astronomical discovery engine.

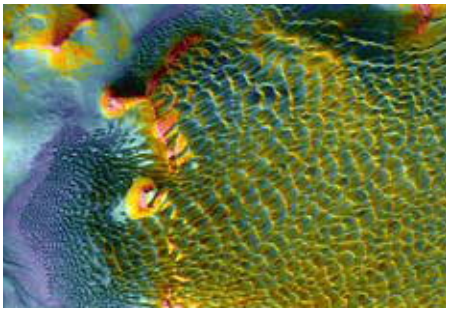
Visions of kilometer-long instruments figure prominently in NASA's Beyond Einstein program. Its Laser Interferometer Space Antenna (LISA), scheduled for launch in 2015, is a good example. This gravitational-wave detector includes three spacecraft designed to maintain their orientation to each other. The trio communicates by laser beams over a distance of 3.1 million miles (5 million kilometers). Changes in the beam lengths will signal the passage of a gravity wave.

But first come more modest tests over more convenient ranges. Because the SPHERES hardware is basic, having a human nearby to tinker with it can be critical to making it work at all. This is why designers decided to try out SPHERES inside ISS. Validation of this strategy came when the first test flights in mid-May encountered a number of hardware and software problems. Any one of them would have aborted an autonomous test, but the astronaut operating the experiment easily fixed every one of them. The choice of an interior "proving ground" made other design features possible.

In recent decades, space technology has provided the means to achieve unexpectedly precise and long-term pointing of spacecraft. Such advances are why Hubble was deployed in free space rather than (as early theorists expected) constructed on the lunar surface's firm foundation. SPHERES takes this a step further. It demonstrates precise control of multiple space objects at significant ranges from each other (and from Earth). If the concept proves itself, the technology will free future telescope arrays from the need to use a planetary surface at all. — **JAMES OBERG**

Storm probes

NASA's twin Radiation Belt Storm Probes, scheduled for a 2012 launch, will study how solar activity affects high-energy electrons and ions trapped in Earth's radiation belts. Detailed design began this summer.



NASA/JPL/ASU

RABE CRATER. **False-color sand dunes give the martian crater's floor a washerboard look.**

Gold-flecked crater

Visible and thermal scans from NASA's Mars Odyssey reveal heat patterns in Rabe Crater's sand dunes. Dune crests (gold) retain daytime warmth almost as well as rocky outcrops (red). The 67-mile-wide (108 kilometers) crater lies west of Mars' Hellas basin. — **F. R.**

Low-tech path to an exoplanet

A team of professional and amateur astronomers led by Peter McCullough of the Space Telescope Science Institute (STScI) in Baltimore has found its first extrasolar planet. The group's innovative telescope sports two 8-inch (200 millimeters) telephoto camera lenses mounted side by side like binoculars.

The team calls the instrument the XO Telescope. Planet-searchers in Hawaii used the instrument to observe tens of thousands of bright stars nightly from September 2003 to September 2005. A computer program sifted through the data and identified a few hundred stars undergoing possible planetary transits.

Last June and July, amateur astronomers made follow-up observations of likely candidate stars. They confirmed one case where brightness changes were caused by an object transiting the star, which the team designated XO-1. Radial-velocity measurements at McDonald Observatory in Texas on February 16 verified the transiting object is an extrasolar planet (now dubbed XO-1b). — **L. L.**

NASA/SWIFT/XRT/UNIV. OF LEICESTER/RICHARD WILLINGALE

BREAKING AWAY. **In early May, as Comet 73P/Schwassmann-Wachmann 3 glided past the Ring Nebula (M57), NASA's Swift satellite imaged the pair at X-ray wavelengths.**

Comet breakup sends X rays flying

NASA's Swift satellite detected X rays from Comet 73P/Schwassmann-Wachmann 3's crumbling fragments as they paraded past Earth in early May. Scientists suggest the X rays arose as subatomic particles in the solar wind interacted with cometary material.

"During its 1996 passage, [the comet] broke apart," says Swift team member Scott Porter of NASA's Goddard Space Flight Center in Greenbelt, Maryland. Comet 73P is the brightest comet ever observed at X-ray wavelengths. "Now, we are tracking about three-dozen fragments," says Porter. "The X rays being produced provide information never before revealed."

Other space-based instruments also got in on the act, including NASA's Chandra X-ray Observatory, the European Space Agency's XMM-Newton X-ray Observatory, and Japan's Suzaku X-ray satellite. Scientists hope X-ray observations will provide more information about the composition of both the solar wind and the comet and how they interact with one another. — **L. L.**

LSST home Chile's 8,800-foot-high (2,682 meters) Cerro Pachón will host the 27.5-foot (8.4m) Large Synoptic Survey Telescope, which is expected to see first light in 2012.

NASA/JPL/MALIN SPACE SCIENCE SYSTEMS

SCALLOPED DUNES. Frost enhances view.

A frosty blanket covers Mars dunes

A martian dune field takes on a strange aspect during northern winter, when a layer of carbon-dioxide frost covers it. Sunlight illuminates this 1.9-mile-wide (3 kilometer) scene from the lower left. Slopes facing toward the upper right appear sunlit because more frost accumulates on the shaded side; the result is a peculiar scalloped effect. NASA released this Mars Global Surveyor (MGS) view of polar shells May 21. The dune field is located near 76.3° north, 264.3° west. — **L. L.**

Swift captures RS Oph flare-up

The white dwarf in the RS Ophiuchi (RS Oph) system orbits its red-giant companion so closely, it lies within the giant's atmosphere. So concludes Michael Bode of Liverpool John Moores University in England, who led a team using NASA's Swift satellite to monitor the system's latest flare-up.

RS Oph generates an outburst every 20 years. Matter from the red giant accumulates on the object's surface and, eventually, detonates in a massive thermonuclear blast. The blast creates temperatures up to 180 million degrees Fahrenheit (100 million degrees Celsius) — almost 10 times hotter than the Sun's core.

A brilliant flash results when the blast's fast-moving debris strikes the red giant's atmosphere. Bode says a surprising secondary brightness increase may arise because the blast creates a hole in the red giant's atmosphere. This gave astronomers a briefly unimpeded view of the white dwarf itself. Bode presented his team's findings April 7 at the Royal Astronomical Society meeting in Leicester, England. — **L. L.**

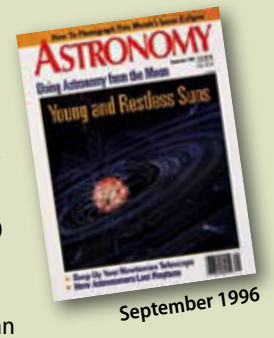
25 years ago in *Astronomy*

September 1981

Gary Kronk's "Mr. Halley's Hairy Star" profiled Halley's Comet, 5 years before its 1986 appearance. It told the tale of 18th-century astronomers' and mathematicians' efforts to accurately predict when Comet Halley would make its closest approach (perihelion) to the Sun when it returned in 1758.

Although Edmond Halley correctly calculated the comet's 76-year orbit period, his estimate for when it would reach perihelion was off by 32 days. This miscalculation, coupled with the inevitable march of science, inspired an informal competition to predict the comet's precise behavior. Speaking of which: only 55 years until Halley's next return!

10 years ago in *Astronomy*



September 1996

"Neptune's discovery 150 years later" by William Sheehan and Richard Baum told of how German astronomer Johann Gottfried Galle and French mathematician Urbain Jean Joseph Le Verrier received credit for discovering Neptune — even though Englishman John Couch Adams determined the unknown planet's position. Adams pinpointed Neptune's position in September 1845 — 9 months before Le Verrier published his prediction, and a full year before Galle had even sighted the mystery planet.

Adams never published his result. An astronomer charged with validating the predictions twice observed Neptune, but outdated star charts kept him from realizing what he was seeing.

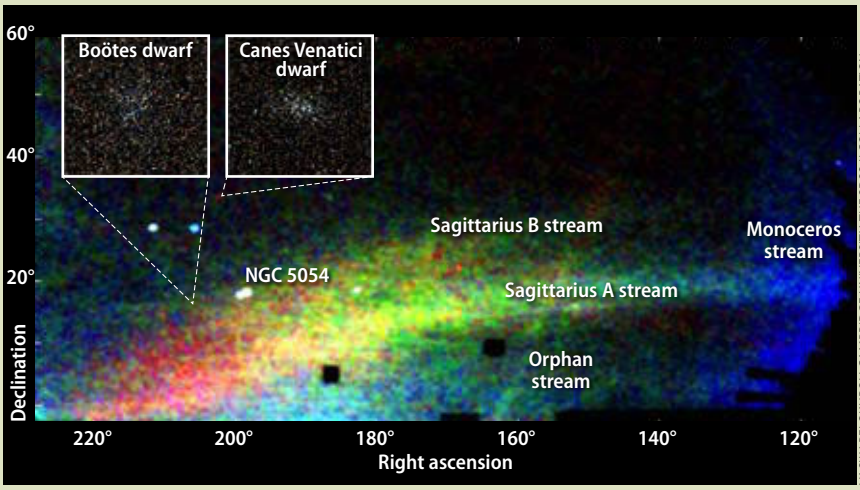
BRIEFCASE

Crash report

A June 13 report blames the 2004 crash of NASA's Genesis probe on engineers. Switches used to deploy the parachutes were put in backward. — **F. R.**

Earmarks drain NASA

Lawmakers tacked nearly $570 million in pet-project earmarks onto the space agency's 2007 spending bill. The practice is "draining NASA's lifeblood," complains U.S. Senator Bill Nelson. The record amount is about one-third the cost of a shuttle launch. — **F. R.**



VASILY BELOKUROV, CAMBRIDGE UNIVERSITY; THE SDSS-II COLLABORATION

SDSS finds new Milky Way satellites

STARRY TRAILS. Sloan Digital Sky Survey data reveal background structure formed as the Milky Way Galaxy tore apart globular clusters and companion galaxies.

Vasily Belokurov and Daniel Zucker of Cambridge University, England, led a team that created the clearest-ever view of stars streaming near the Milky Way's north pole. In the process, they found two new satellites of our galaxy.

The scientists examined Sloan Digital Sky Survey (SDSS) data spanning nearly one-quarter of the sky. They removed red, nearby stars in order to see distant structures. What remained was crisscrossed with so many distinct starry trails, the team dubbed it the "Field of Streams." These starry streams form as the Milky Way's gravity shreds small satellite galaxies and globular star clusters.

While poring over the region, Zucker noticed an obvious overdensity of stars in the constellation Canes Venatici. The newfound dwarf galaxy is about 640,000 light-years away — a contender for our galaxy's most distant companion.

A few hours after Zucker e-mailed the discovery to Belokurov, Belokurov in turn reported the discovery of a new, even fainter dwarf. The small galaxy lies 196,000 light-years away in Boötes. Shining with the luminosity of 100,000 Suns, the Boötes dwarf is the faintest galaxy yet discovered.

The Boötes dwarf is about 720 light-years across. The Canes Venatici dwarf spans 1,790 light-years. — **F. R.**

NASA/JPL-CALTECH/L. REBULL (SSC)

CLASS ACT. Students discovered new stars while observing the Witch Head Nebula.

Students, teachers make Spitzer finds

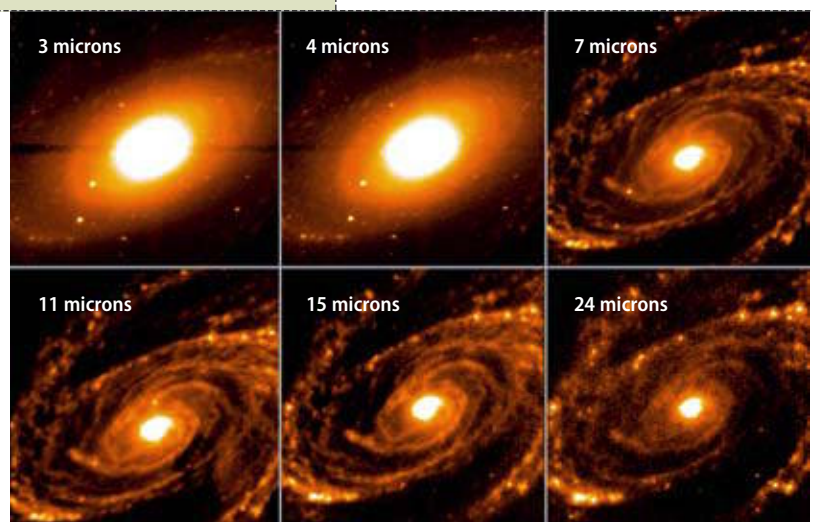
Teens and their teachers quadrupled the number of known stars in Orion's Witch Head Nebula, 800 light-years away. In 2005, the team used NASA's Spitzer Space Telescope as part of Spitzer's Research Program for Students and Teachers and located 12 infant stars.

"Seeing newborn stars that no one had seen this clearly before was thrilling," says Cynthia Wheeler, a science teacher at Burbank High School in San Antonio. The find won the group another 11 hours of Spitzer observing time. — **L. L.**

Akari sees first light

Japan's Akari infrared satellite returned its first images April 13, 2006. The reflection nebula IC 4954, which lies 6,000 light-years away, and galaxy M81 — 12 million light-years distant — were the subjects of the satellite's first portraits.

Akari has begun the first phase of its mission, during which it will perform a comprehensive survey of the entire sky in six infrared wavelengths (3, 4, 7, 11, 15, and 24 microns). "Akari is ... an all-sky survey in the far-infrared with improved sensitivity and greatly improved resolution compared to the IRAS [Infrared Astronomical Satellite] mission of the 1980s," says Michael Rowan-Robinson at Imperial College London. "It will be a major step forward at these wavelengths." — **L. L.**

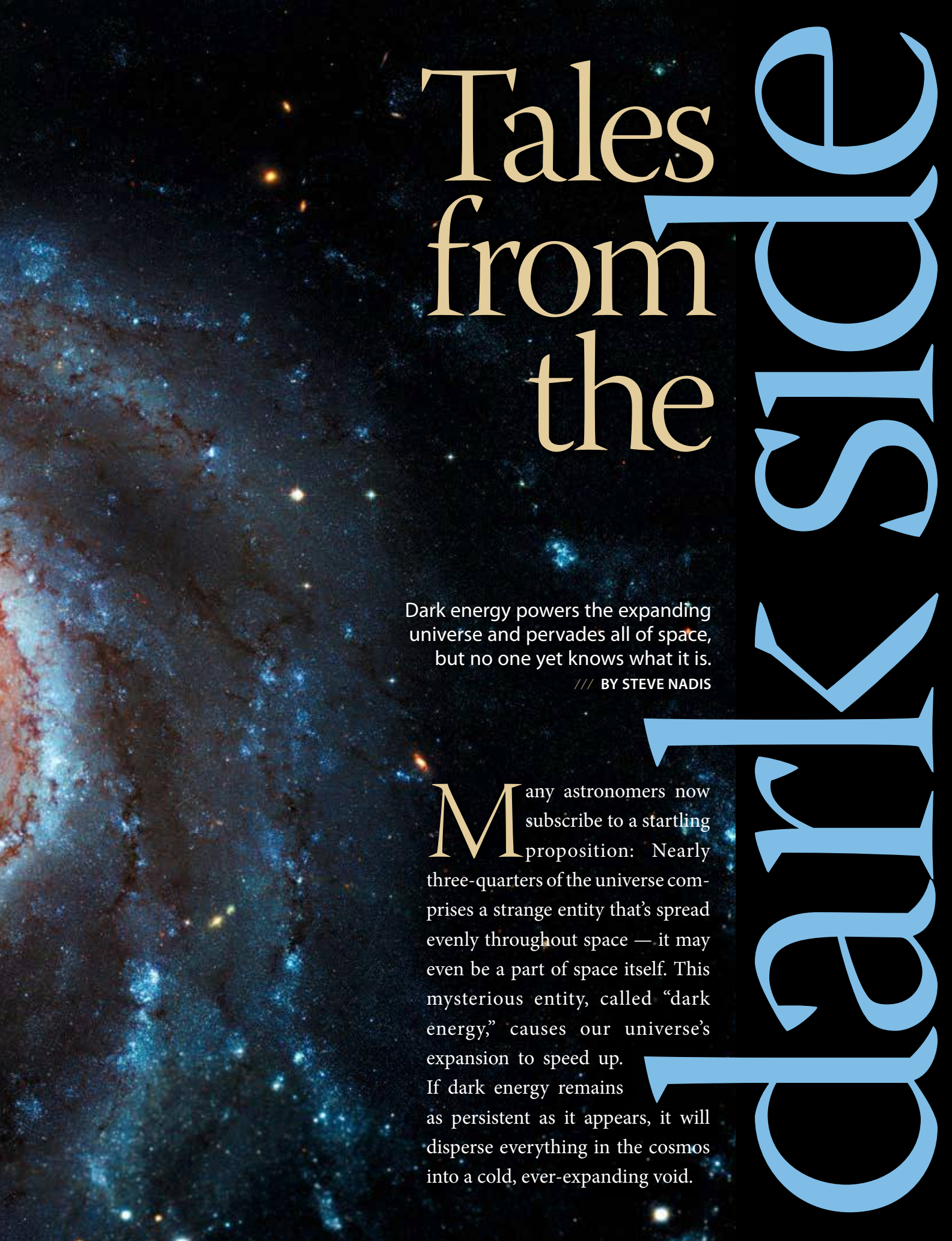


JAXA

WARM GALAXY. Akari recorded galaxy M81 in various infrared wavelengths. Images taken at 3 and 4 microns reveal the stellar distribution in the galaxy's inner regions, while longer wavelengths show dusty star-forming regions.

AS COMMANDING as massive spiral galaxy M101 appears, it and everything else we see in the universe amount to only 4 percent of the cosmos' total content. Dark matter, the as-yet-unidentified material surrounding galaxies, makes up 22 percent. Dark energy, the strange force that's pushing the universe apart, makes up 74 percent of the cosmos.

NASA/ESA



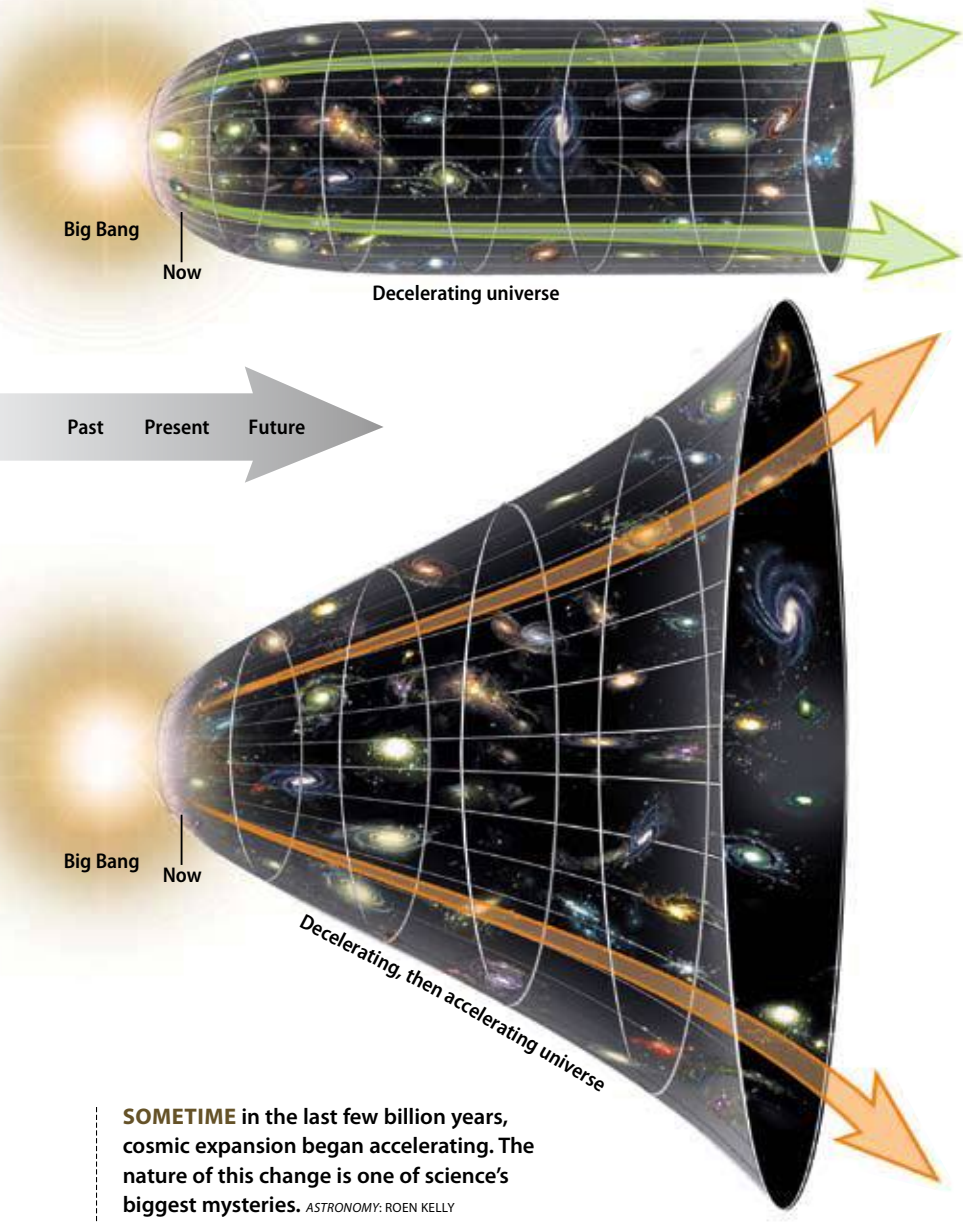
Tales from the dark side

Dark energy powers the expanding universe and pervades all of space, but no one yet knows what it is.

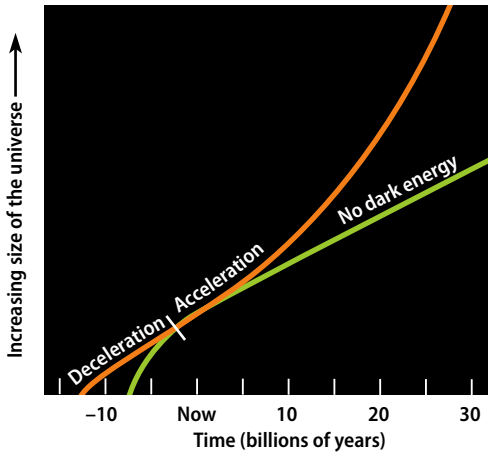
/// BY STEVE NADIS

Many astronomers now subscribe to a startling proposition: Nearly three-quarters of the universe comprises a strange entity that's spread evenly throughout space — it may even be a part of space itself. This mysterious entity, called "dark energy," causes our universe's expansion to speed up. If dark energy remains as persistent as it appears, it will disperse everything in the cosmos into a cold, ever-expanding void.

A cosmological turning point



SOMETIME in the last few billion years, cosmic expansion began accelerating. The nature of this change is one of science's biggest mysteries. *ASTRONOMY:* ROEN KELLY



UNTIL 1998, cosmologists thought the universe was slowly decelerating as the gravity of all matter within it slowed expansion. Since then, astronomers have accumulated evidence that the expansion began accelerating as dark energy counters gravity's tug. The most recent data indicate cosmic acceleration will continue forever. *ASTRONOMY:* ROEN KELLY

This strange scenario has gained credence since 1998, when studies of distant type Ia supernovae suggested these stellar explosions, which are known for uniform energy output, were dimmer — and thus farther away — than expected for their redshifts. Astronomers proposed that an unseen force was causing the universe to expand at an accelerated clip. Cosmic microwave background (CMB) measurements from the Wilkinson Microwave Anisotropy Probe (WMAP) and other experiments supported this notion.

"There was a moment of disbelief," acknowledges Saul Perlmutter of the Lawrence Berkeley National Laboratory, who leads one of the supernova-study teams. But as data filtered in from multiple fronts, astronomers moved from denial to grudging acceptance. Dark energy, which many consider to be the deepest, most important mystery in all of science, was here to stay.

"Dark energy is not predicted by the physics we understand," says Adam Riess of the Space Telescope Science Institute in Baltimore. "So, learning about it will almost certainly lead us to something new and exotic."

Groping in the dark

Astronomers have three leading explanations for dark energy, and deciding among them will be a major focus of cosmologists for years. The first is the cosmological constant, proposed (and later recanted) by Albert Einstein. In this view, dark energy is an intrinsic, uniform property of space.

The second idea, called quintessence, involves an unidentified energy field of varying strength that fills space like a fog. Scientists envision this unidentified energy as similar to that which drove inflation, the rapid burst of expansion in the instant following the Big Bang.

The third alternative? Dark energy is an illusion. Instead, the effects we see result from a breakdown in Einstein's theory of gravity over the largest distance scales. Most scientists have focused on the existence of dark energy. But this "modified gravity" alternative deserves serious consideration as well, says Princeton University's David Spergel. The right explanation may turn out to be "none of the above."

While these competing ideas differ dramatically, says Daniel Eisenstein of the University of Arizona, "From an observational standpoint, the differences could be extremely subtle. You can construct all kinds of models that give you answers that are close to the cosmological constant. The only way to tell the difference is by doing the measurements extremely accurately."

It won't be easy, Perlmutter admits. "It took us 10 years to realize the universe is accelerating, and it will take at least as long to figure out what's behind it," he says.

Steve Nadis *is a frequent contributor to* Astronomy. *His previous article was "What happens when black holes collide?" in the May issue.*

"The good news is that we have ways of attacking the problem."

"We need to throw everything we can at this problem," insists Robert Nichol of the University of Portsmouth, England. "We need to throw the kitchen sink at it." All told, astronomers are pursuing roughly a dozen different approaches. So far, the big payoff has come from supernovae, which provide the only direct measure of cosmic expansion.

Standard candles

To chart the universe's expansion history, astronomers measure a supernova's luminosity and redshift. Because each type Ia supernova releases about the same energy, each blast's luminosity reflects its distance from Earth. The redshift tells us how much the light has stretched (how much the universe has expanded) during its travel. By looking at supernovae over a broad redshift range, astronomers discovered the universe's expansion rate has varied.

The focus now, says Riess, is to push back to higher redshifts in order to measure the acceleration's onset. The Hubble Space Telescope is the best tool for finding distant supernovae. But a dedicated space instrument, such as the proposed Supernova/Acceleration Probe (SNAP), would hasten the process. As now envisioned, SNAP would best Hubble with both a larger field of view (0.7°) and a billion-pixel imager.

"IT TOOK US 10 YEARS to realize the universe is accelerating, and it will take at least as long to figure out what's behind it." — *Saul Perlmutter*

When did dark energy's push overtake gravity's pull? Based on Hubble observations, Riess believes the balance tipped about 5 billion years ago, but he'd like to know exactly when the changeover occurred because predictions differ among theories. The transition occurs earlier in quintessence models, for instance, than in cosmological-constant models.

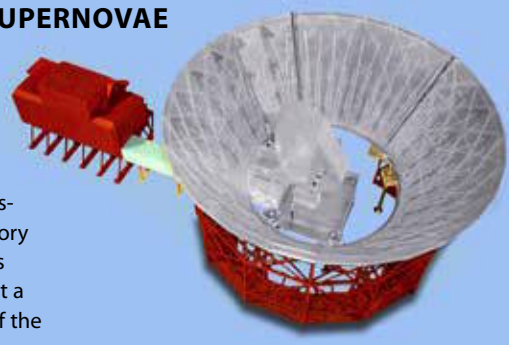
DESPERATELY SEEKING SUPERNOVAE

The most far-flung supernovae are extremely faint and detectable only in wavelengths blocked by Earth's atmosphere. NASA and the U.S. Department of Energy are sponsoring the Joint Dark Energy Mission (JDEM), a space-borne observatory dedicated to unlocking dark energy's secrets. JDEM, to be launched at least a decade from now, will employ one of the following designs:

• Dark Energy Space Telescope (DESTINY). This project, headed by Jon Morse at NASA's Goddard Space Flight Center, is a 1.8-meter near-infrared space telescope dedicated to surveying high-redshift supernovae.

• Joint Efficient Dark-energy Investigation (JEDI). This 2m space telescope would monitor 14,000 type Ia supernovae, capture redshifts for more than 100 million galaxies, and conduct a weak-lensing survey. Yun Wang of the University of Oklahoma heads up JEDI.

• Supernova/Acceleration Probe (SNAP). This 2m optical and near-infrared telescope would discover and measure the spectra of 6,000 distant supernovae during its 3-year mission. It would also perform a weak-lensing survey. Saul Perlmutter, Lawrence Berkeley Laboratory, is the principal investigator. — *S. N.*



THE SOUTH Pole Telescope, now under construction, will observe the sky at millimeter and longer wavelengths, a region between radio and the infrared. Its first key project, a wide-area survey of galaxy clusters using the Sunyaev-Zeldovich effect, will complement supernova studies. UNIVERSITY OF CHICAGO

New surveys now in progress will amass bigger and more homogenous data sets. The ESSENCE program at the Cerro Tololo International Observatory in Chile is midway through a 5-year project to measure 200 supernovae at intermediate redshifts. Another 5-year effort, the Supernova Legacy Survey at the Canada-France-Hawaii Telescope on Mauna Kea in Hawaii, is designed to detect and monitor 1,000 high-redshift supernovae. "It's hard to say how big a sample we need," notes Riess. "It depends on what nature has in store for us."

Meanwhile, astronomers need to understand type Ia supernovae better to make them truly reliable dark-energy probes. "There weren't as many heavy metals in the early universe, which could lead to a difference in explosion physics — and, hence, brightness — that might fool us," explains Harvard University physicist Christopher Stubbs. Astronomers are trying to address this concern through close scrutiny of supernova spectra.

Wiggling baryons

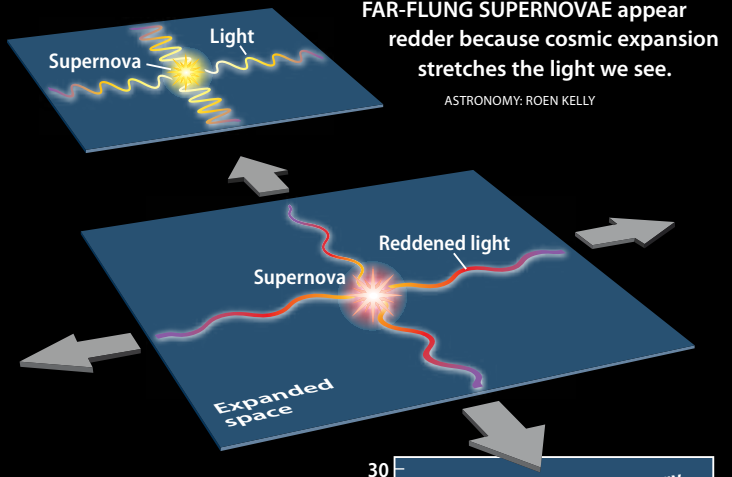
One method for exploring dark energy potentially has the highest precision, according to University of Oklahoma cosmologist Yun Wang. It involves "baryonic acoustic oscillations" — fluctuations in the distribution of photons and particles of ordinary matter (baryons) caused by sound waves sloshing around in the early universe. Think of these fluctuations as the ripples made by tossing a pebble in a glass-smooth pond. The waves left a faint imprint in the distribution of galaxies. The galaxies, in other words, tend to space themselves on a distinct physical scale. They constitute a "standard ruler," just as type Ia supernovae serve as standard candles.

The basic approach is to find a large number of galaxies with the same redshift. Knowing that the ruler's length correlates with redshift, observers then determine the scale of peak clumpiness. By measuring the angle this "preferred length" subtends, scientists say they can determine the distance to the galaxy. The distance-redshift relation, as with supernovae, tells researchers how dark energy has influenced the universe's expansion.

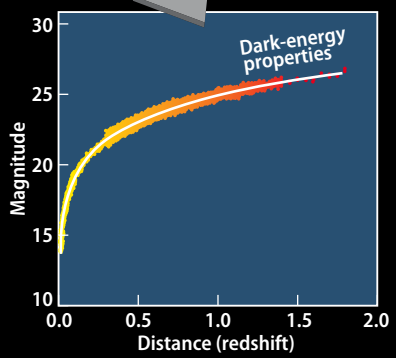
Daniel Eisenstein and colleagues first measured these baryon wiggles last year in Sloan Digital Sky Survey data. The result validates the supernova findings through different means, but it will take a more

Four ways to target dark energy

High-redshift supernovae

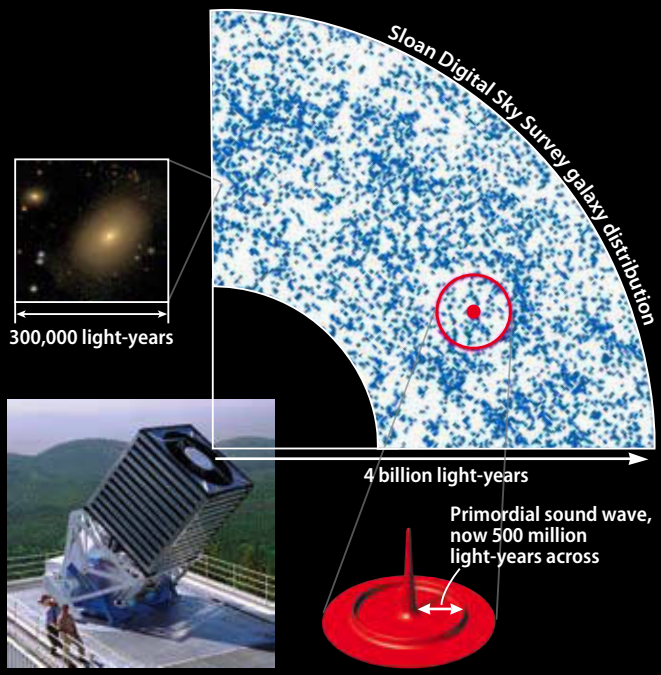


FAR-FLUNG SUPERNOVAE appear redder because cosmic expansion stretches the light we see. ASTRONOMY: ROEN KELLY



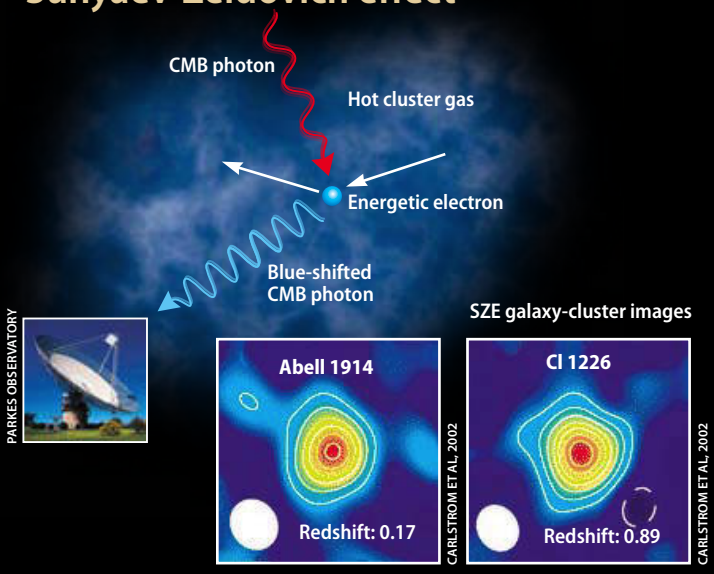
THE MOST DISTANT type Ia supernovae look dimmer than they should, which indicates they're located farther from us than expected from the standard energy of these blasts. SN 1997ff, which lies at redshift 1.7, is the farthest such supernova known, but most type Ia types have redshifts less than 1. In a single year, a space telescope dedicated to finding supernovae could identify thousands at redshift 1.5 and beyond. This would reveal much about dark energy's properties. *ASTRONOMY:* ROEN KELLY

Baryonic acoustic oscillations


Sloan Digital Sky Survey galaxy distribution
300,000 light-years
4 billion light-years
Primordial sound wave, now 500 million light-years across

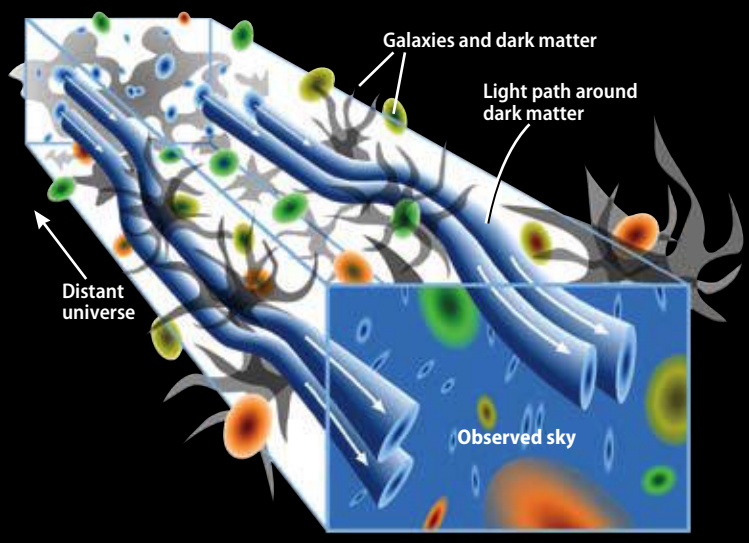
SOUND WAVES in the early universe left their imprint in the CMB. Last year, Daniel Eisenstein and colleagues announced the discovery of corresponding ripples in the distribution of galaxies mapped as part of the Sloan Digital Sky Survey (SDSS). Because the ripples appear both in relatively nearby galaxy groups and the high-redshift CMB, they offer a geometric measure of the relative distance between these widely separated redshifts — and more clues to cosmic acceleration. SDSS

Sunyaev-Zeldovich effect



HOT GAS in massive galaxy clusters distorts the cosmic microwave background (CMB). The gas' fast-moving electrons can give a CMB photon an energy boost. This distortion of the CMB is called the Sunyaev-Zeldovich effect (SZE). *ASTRONOMY:* ROEN KELLY

Weak lensing



LIGHT FROM the distant universe wends its way through gravitational distortions caused by regions of dark matter. This creates a slight shear in individual galaxy images — so slight, it's apparent only when astronomers compare large numbers of galaxies. LSST CORPORATION

precise redshift survey, drawing on more galaxies in a larger volume of space, to probe dark energy further. "With Sloan, we detected the effect with 4-percent precision, but we'd like to get to 1-percent precision," Eisenstein says.

Two experiments are planned to achieve this goal. The Hobby-Eberly Telescope Dark Energy Experiment will survey a million galaxies out to redshift 3, starting in 2008. For comparison, this is almost double the 1.7 redshift of SN 1997ff, the most distant supernova known. Eisenstein is working with a competing group that hopes to install a Wide-Field Multi-Object Spectrograph (WFMOS) on Hawaii's Subaru or Gemini North telescope. First light for the new instrument is scheduled for 2013.

Clusters count

Galaxy clusters offer insights to the problem, too. One method exploits the fact that the CMB spectrum is distorted in characteristic ways when its microwave photons interact with the hot gas inside clusters. The phenomenon, which cools long-wavelength photons and energizes short-wavelength photons, is called the Sunyaev-Zeldovich effect (SZE).

The South Pole Telescope (SPT), a millimeter- and submillimeter-wavelength instrument being built in Antarctica to search for this effect, is expected to begin observations in 2007. SPT designers expect to discover up to 30,000 new clusters with masses greater than 100 trillion Suns.

Once the survey identifies targets, optical observers will measure the clusters' redshifts so astronomers can determine how the number of clusters changes as a function of redshift. This, in turn, will show how dark energy evolved as the universe aged: The number of clusters is sensitive to whether gravity or dark energy is the dominant cosmic force.

High-energy astronomers are doing something similar using facilities like NASA's Chandra X-ray Observatory. "We see the cluster gas directly with X rays, whereas the SZE approach sees how the gas affects the CMB," explains Stanford University's Steven Allen.

Through a lens weakly

Any concentration of mass bends the light of galaxies behind it. Sometimes this occurs in spectacular fashion, producing rings or double images in the sky. So-called weak gravitational lensing is more common, causing subtle effects that can be observed only statistically. In regions where matter is clustered, galaxy shapes become stretched a tiny bit, say 1 percent. This modest shearing of galaxy images is detectable because it generally occurs in a single direction. But you have to look at millions or, preferably, billions of galaxies to see a pattern.

Because dark energy affects the universe's expansion rate, it affects the distances between the source, lensing galaxy, and us. By changing these distances, dark energy alters the distortion pattern's strength, which is something scientists can measure.

Astronomers first documented the phenomenon of cosmic shearing in 2000, so the technique is still new. The best effort, according to University of Pennsylvania physicist Gary Bernstein, involved a survey of about 2 million galaxies over 75 square degrees. "We're just starting to measure dark energy, but the more galaxies we get, the better we'll do," he says. "The goal is to see as much sky as possible."

The next step is the Legacy Survey at Mauna Kea — a 5-year effort begun in 2003. It aims to measure 20 million galaxies over 200 square degrees of sky. The 8.4-meter Large Synoptic Survey Telescope (LSST), scheduled to begin operation in 2012 at a site yet to be named, is even more ambitious. This scope will survey a billion or so galaxies covering 30,000 square degrees. With this unparalleled combination of aperture and field of view, weak lensing — despite its name — could become powerful indeed.

> "WE'RE JUST STARTING to measure dark energy, but the more galaxies we get, the better we'll do."
> — *Gary Bernstein*

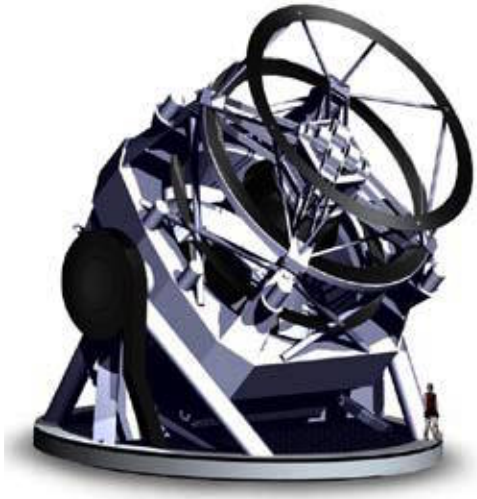
Grand synthesis

A proposal called the Dark Energy Survey would gather data on 300 million galaxies and merge all of these techniques into a coherent overview. "These techniques complement each other well," says Joshua Frieman of the University of Chicago. "They suffer from different sources of error, so, if they agree, that gives you confidence in the result." The survey could begin in 2009 with observations from Cerro Tololo's 4-meter Blanco Telescope.

Harvard's Christopher Stubbs agrees. "Supernovae misbehaving at high redshift won't affect the density of clusters, nor will observations of large-scale-structure formation affect supernova luminosities."

Owing to the difficulty in making these observations, no one will believe an answer unless it's obtained using more than one investigative method. Data so far show dark energy to be a much weaker form of Einstein's cosmological constant, but the precision isn't high enough to rule out other interpretations.

As University of Chicago cosmologist Sean Carroll puts it, "All we can do is keep improving the precision until we lose interest." Astronomers are far from that point now. "We are incredibly lucky to be working just at the moment when the pieces of the cosmic jigsaw puzzle are falling into place," he says. And dark energy constitutes the biggest puzzle piece of all.



THE LARGE Synoptic Survey Telescope is a ground-based, wide-field, 8.4-meter instrument designed to image the entire available sky every 3 nights. Its superb images will help astronomers trace the shapes of remote galaxies — and see distortions produced by dark matter. This will provide an important and independent measure of dark energy. LSST CORPORATION

ONLINE EXTRA Is dark energy just a quirk of gravity? See www.astronomy.com/toc

COSMOLOGY

SPECIAL REPORT

A wrinkle in

Studying gravitational waves from our universe's birth, every cosmologist's dream, may be close to reality. /// BY ADAM FRANK

Forty-two years ago, astronomers first heard the Big Bang's echo. The cosmic microwave background, or CMB, is relic radiation from the universe's birth, a fossil formed 380,000 years after the Big Bang. Recognition of the CMB marked the beginning of modern cosmology, and it's still telling astronomers much about the early universe. ❮ In March, scientists using NASA's Wilkinson Microwave Anisotropy Probe (WMAP) released the most detailed portrait of the CMB yet. By looking at the preferred directions of CMB signals, astronomers showed the early universe's initial growth spurt, a period called inflation that occurred less than a trillionth of a second after the Big Bang, doesn't match up with some complex inflation scenarios. By eliminating some versions of inflation, a cornerstone of modern cosmology, scientists have begun to pull back the curtain on the universe's first second.

But to probe further into this mysterious time, when the universe expanded at a furious, never-to-be-repeated pace, cosmologists need something new. Now the search is on for gravitational waves, relic ripples in the structure of space and time from the inflation era.

Adam Frank *is an astrophysicist at the University of Rochester in New York and a member of* Astronomy*'s editorial board. He wrote "The first billion years" in the June 2006 issue.*

Ballooning cosmos

Astronomers know how fast the universe is expanding, and they think they have a good idea of how that expansion progressed after the first few seconds following the Big Bang. One of the puzzles facing astronomers studying the CMB was understanding how widely separated regions of space could have the same temperature. Yet, in standard Big Bang models, the finite speed

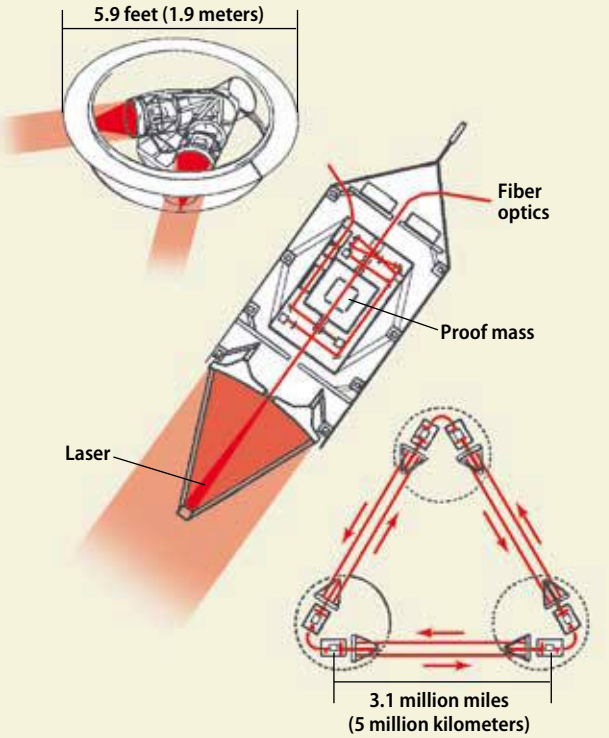
space-time

RIPPLING THROUGH the early universe, gravitational waves carry information from less than a trillionth of a second after the Big Bang. Although no one has yet detected these entities directly, Einstein's general relativity predicts their existence.

DON DIXON FOR *ASTRONOMY*

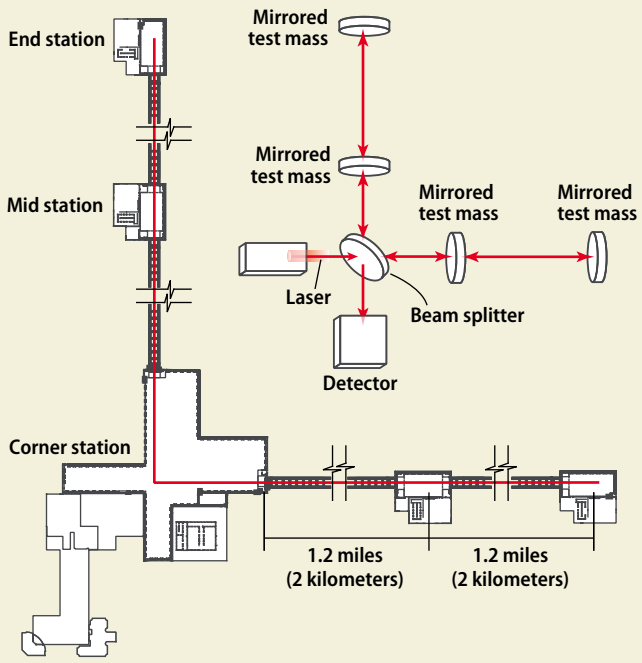
Sensing gravity waves

Laser Interferometer Space Antenna (LISA)



LISA WILL be the first dedicated gravitational-wave observatory in space. This NASA-European Space Agency mission, to launch in 2013, will use three spacecraft to form a triangular interferometer spanning 3.1 million miles (5 million kilometers). Changes in the distance between the spacecraft will signal a passing gravitational wave. *ASTRONOMY*: TERRI FIELD

Laser Interferometer Gravitational-wave Observatory (LIGO)



EACH OF the LIGO detectors sends laser pulses down two 2.5-mile-long (4 km) arms and combines their light. This diagram shows the layout of the Hanford, Washington, observatory. By making laser light travel up and down the arms and interfere with itself, scientists will be able to deduce minute changes in the light's path from a gravity-wave encounter. *ASTRONOMY*: ROEN KELLY

GRAVITATIONAL-WAVE OBSERVATORIES

Project	Location	Arm length
LIGO	Livingston, Louisiana	2.5 miles (4 km)
LIGO	Hanford, Washington	2.5 miles (4 km)
VIRGO	Pisa, Italy	1.9 miles (3 km)
GEO600	Ruthe, Germany	1,968 feet (600 meters)
TAMA	Mitaka, Japan	984 feet (300m)
AIGO	Perth, Australia	262 feet (80m); prototype

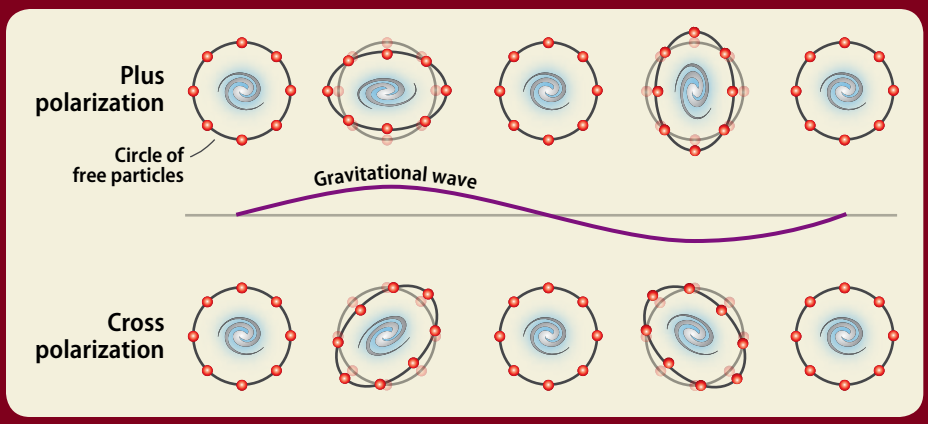
of light makes it impossible for radiation from one side of the expanding universe to reach the opposite side in the 380,000 years before the CMB formed.

This causal conundrum was the monster problem for astronomers and physicists in the 1970s. Their solution was as radical as it was successful.

In 1980, physicist Alan Guth at the Massachusetts Institute of Technology (MIT) suggested a novel addition to the Big Bang's standard story. He supposed that, at some instant following the Big Bang, everything we see in the universe was in causal contact. Signals from one region could reach all others. Information was shared, causes led to effects, thermal variations smoothed out. Conditions became uniform and constant.

Then, argued Guth, came a remarkable instant when the universe "inflated." In a moment, the cosmos ballooned in size by a factor of 10^{43} — that's 1 followed by 43 zeros. To say that many astrophysicists were skeptical about Guth's proposal would be putting it politely. In time, however, his idea took hold. Infla-

How gravitational waves distort space

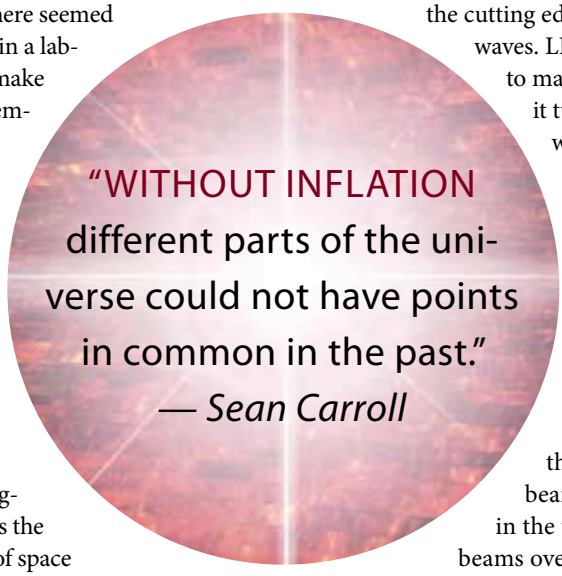


IN GENERAL RELATIVITY, gravitational waves distort the distances between nearby free particles, a property observatories like LIGO and LISA attempt to exploit. A passing wave can be either "plus" polarized (top) or "cross" polarized (bottom). Each type distorts space-time, represented in this illustration by a circle of free particles, in a particular way. The distortions shown here are about 20 percent — about a billion trillion times greater than the effect LIGO seeks. *ASTRONOMY:* ROEN KELLY

tion solved too many problems for cosmologists to ignore it. "Without inflation," explains University of Chicago cosmologist Sean Carroll, "different parts of the universe could not have points in common in the past." Inflation cures this dilemma.

In the years following Guth's paper, interest in inflation theory went through its own hyper-expansion. Using ideas gleaned from particle physics, cosmologists explored different ways to turn inflation on and off. There are now many variations on the basic idea.

Science has always struck a balance between high-flying theoretical speculation and the grounding specifics of real-world data. Because inflation theory concerns itself with impossibly small sizes and impossibly short time spans, there seemed to be little hope for ever testing its ideas in a laboratory. A scientific theory that cannot make contact with observational data is problematic. In time, though, researchers began to realize that, like the CMB photons rattling around the universe, inflation too would leave detectable relics.



Einstein's waves

Inflation's fossil signals — gravitational waves — are almost as exotic as inflation itself. Gravitational waves are ripples in the structure of space and time. They are a key legacy of Einstein's general theory of relativity. Einstein recognized that gravity could be understood as the warping of a 4-dimensional continuum of space and time (space-time) rather than as a force between masses. For Einstein, space was not the empty stage on which the drama of physics plays out. Instead, it is a principal actor.

Space-time for Einstein is a stretchable fabric that underpins physical reality. The more matter that collects at any location, the more space-time warps, and the more other bodies respond to that bending. Einstein's grand theory also predicts waves of gravity that propagate across space-time like ripples on a pond.

Any gravitational disturbance, meaning any movement of mass, will produce gravity waves, and the more mass involved, the stronger the waves. If two black holes collide, for example, powerful waves ripple outward, stretching and bending space wherever they pass. The waves' intensities diminish as they travel.

Inflation must have been a pretty violent and dramatic rearrangement of matter, energy, and space-time itself. So, it makes sense inflation would have produced a riot of gravity waves. Detecting them — well, that's another matter.

A feel for the cosmos

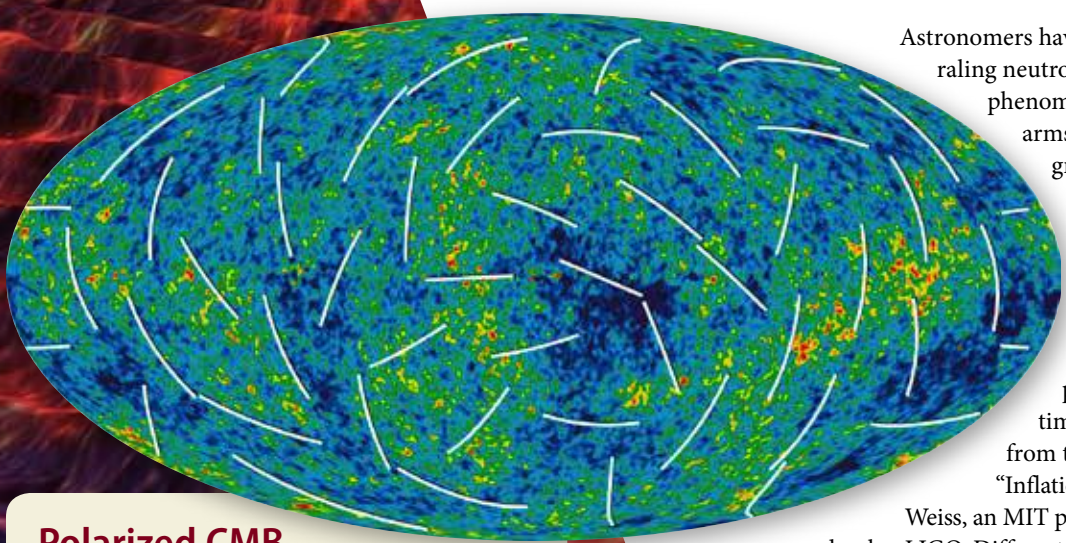
The Laser Interferometer Gravitational-wave Observatory (LIGO) — one detector in Louisiana, one in Washington — represents the cutting edge of scientists' attempts to "feel" gravity waves. LIGO's task isn't easy. While it may be news to many of us bound to Earth's surface, gravity, it turns out, is a weak force. Detecting gravity waves from even relatively nearby (astronomically speaking) cataclysms like merging black holes requires an instrument that can detect the most minute distortions of space.

Each LIGO observatory uses two lasers set at a right angle in an "L" shape. Each beam traverses a 2.5-mile-long (4 kilometers) tube. The beams continuously travel back and forth along the tube. By combining light from the two beams, scientists can sense minute changes in the tube lengths encoded in the way the beams overlap. These small changes in tube length signal that a gravity wave has passed. The expected changes in length are as small as one part in 10 billion trillion (10^{22}) — equivalent to seeing Saturn move closer to the Sun by the diameter of a single hydrogen atom.

LIGO began operation a few years ago and, while no gravity waves have been found yet, scientists aren't disappointed. They are gradually increasing the detectors' sensitivity by reducing various sources of noise that could mask a gravitational signal. Meanwhile, similar detectors in Germany, Italy, and Japan have emerged, and cooperative efforts with these facilities are under way.

Black-hole death spiral rumples space-time

THIS SEQUENCE from a simulation of merging black holes (seen here as spikes) shows how the sudden change of shape and mass creates a pulse of gravitational radiation that propagates outward across space-time. Recent advances in computational techniques, sought for 30



Polarized CMB

AFTER 3 YEARS of studying the cosmic microwave background (CMB), NASA's WMAP observed how microwaves are polarized across the sky. Colors indicate warmer (red) and cooler (blue) spots. The white bars show the preferred orientations, or polarization, of CMB radiation. This information provides new clues about events that transpired in the cosmos' first trillionth of a second.

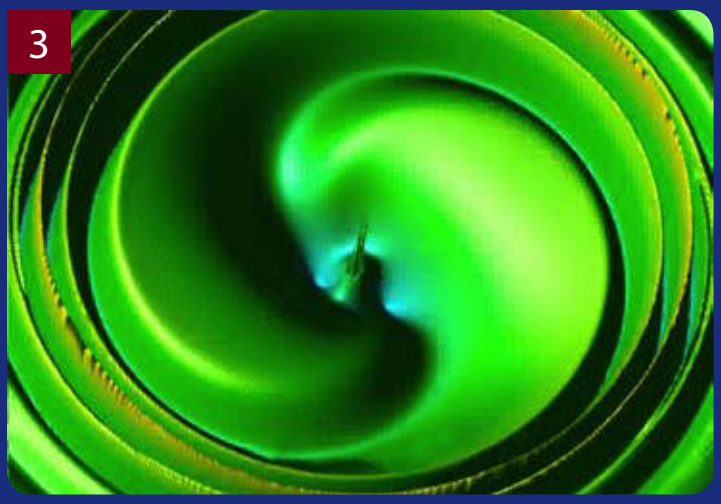
NASA/WMAP SCIENCE TEAM

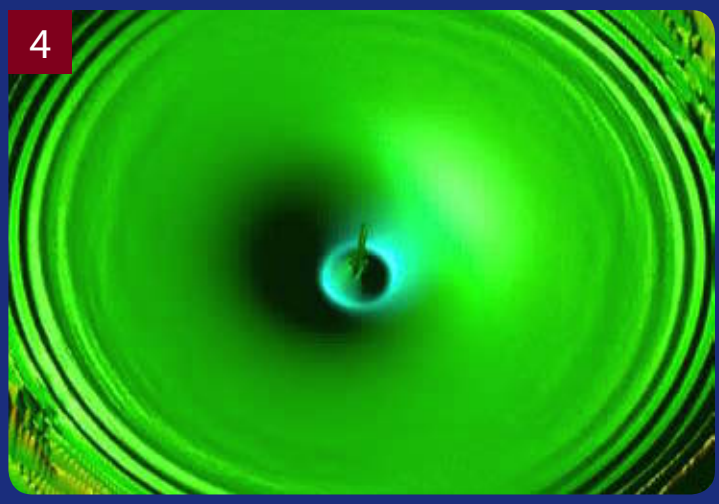
Astronomers have modeled supernovae, inspiraling neutron stars, black holes, and other phenomena to understand how LIGO's arms will stretch and shrink when a gravity wave passes by. These events produce a discrete pulse of gravitational waves. But there also should be a background of gravitational waves from inflation. Whenever and wherever LIGO looks, it should pick up the ringing of space-time due to gravity waves left over from the inflationary epoch.

"Inflation is kind of noisy," says Rainer Weiss, an MIT physics professor who has helped develop LIGO. Different versions of inflation produce different amounts of gravity waves, he says, but these theories have one thing in common: They produce random signals. If scientists can detect gravity waves from inflation, the waves could be observed long enough for astronomers to build up a statistical portrait of their character. This information would finally test inflation and let scientists choose among its many flavors.

That "if" is a pretty big one, however. A careful calculation of the strength of inflationary gravity waves dims many astronomers' enthusiasm. "Unfortunately, LIGO will just not be sensitive enough to detect gravity waves from inflation," says Weiss.

Many astronomers pin their hopes for gravity-wave detection on the Laser Interferometer Space Antenna (LISA). This joint NASA-European Space Agency mission is the most ambitious gravitational-wave observatory yet. Scheduled for a 2013 launch, LISA's three laser-ranging satellites will fly 3.1 million miles (5 million kilometers) apart in a tightly controlled





years, enable rigorous calculation of these extreme events. Today's gravity-wave observatories are designed to detect signals like this, but scientists think the equipment is far too insensitive to pick up gravity waves from inflation. CARLOS LOUSTO, UNIVERSITY OF TEXAS, BROWNSVILLE

triangular formation. They'll continually bounce lasers back and forth to detect minute distance changes from one another. But while LISA will give astronomers a powerful new tool for exploring gravitational waves, it too misses the mark for testing inflation.

"The predictions for the strength of gravity waves from 'vanilla' inflation models put them just out of reach of LISA," says Weiss. But he leaves room for a chance of detection with LISA because some inflation models predict stronger gravity waves.

To really pin down the gravity-wave signature of inflation using a direct detection method like LIGO, astronomers will have to dream big. "With three LISAs flying in formation," explains Weiss, "the signal from inflation would be 10 times stronger than the detection limit." LISA's $500 million price tag puts a more ambitious version many years away.

Back to the background

Our best chance to detect gravity waves from inflation comes not from a direct search for ripples in space-time, but by looking for an indirect signal in, of all things, the CMB. The new WMAP results show clearly that CMB photons hold a key property called polarization, which provides clues to what happened during inflation.

Oscillating electric and magnetic fields make up all light waves. Usually, the way these fields are oriented in space is arbitrary, but certain physical conditions can cause these fields to align. The glare of sunlight reflected from ground objects is polarized, which is why polarizing sunglasses help drivers see better.

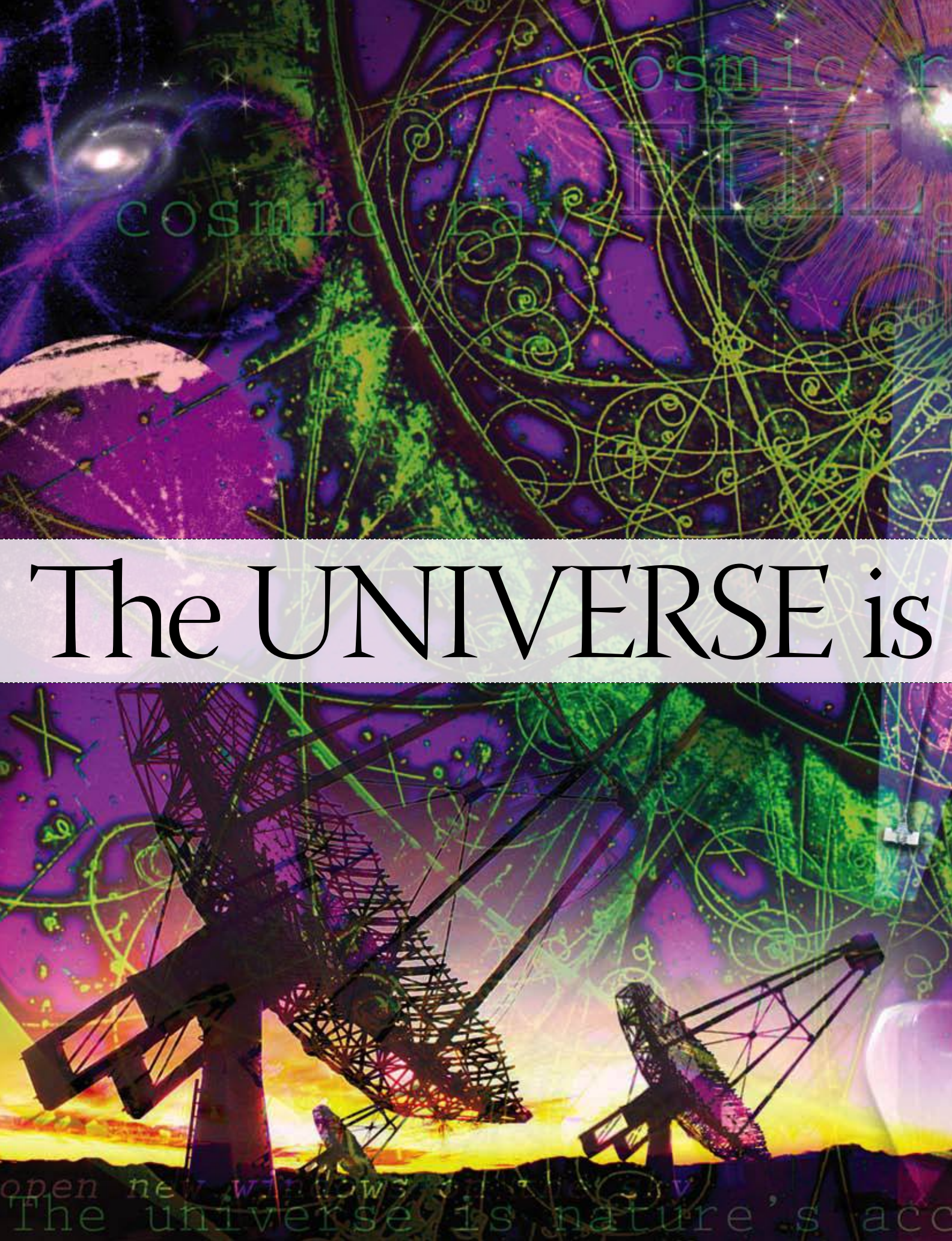
As CMB photons interacted with density fluctuations in the early universe, they developed what cosmologists call E-mode polarization. This was first seen in parts of the CMB from ground-based observatories in 2002 and later confirmed by WMAP. But the probe's second and third year of data extend E-mode polarization measurements across the entire sky and improve their sensitivity. In fact, in sensing these subtle changes, WMAP measured the weakest signals ever detected in the CMB — about 100 times fainter than the temperature signal.

Inflationary gravitational waves also interacted with CMB photons, and cosmologists think the waves also imprinted a so-called B-mode polarization pattern. "This signal is not yet seen, but it's not really a surprise," says Sean Carroll. "The B-mode polarization is expected to be very small, and a lot of effort is going into designing clever new experiments that may someday detect it."

> "IT AMAZES me that we can say anything about what transpired within the first trillionth of a second of the universe, but we can."
> — *Charles Bennett*

Nevertheless, the recent WMAP work has given us our first glimpse into inflation. How? Because it sets limits on how big those unseen B-mode fluctuations can be. This allows cosmologists to discard inflationary scenarios that violate those limits. "It amazes me that we can say anything about what transpired within the first trillionth of a second of the universe, but we can," says Johns Hopkins University's Charles Bennett, WMAP principal investigator.

Whether by directly sensing space-time ripples or detecting their imprint in the CMB, the push toward finding inflation's gravity waves is on. As mind-boggling as the search is, humanity seems poised to explore the first slivers of cosmic time. We are pushing the boundaries of physics and astronomy beyond the realm of imagination to a time when the known universe was the size of an atom. By searching for these relics of inflation, we have begun to explore a frontier that defies our most basic notions of time and space. A


cosmic ray
The UNIVERSE is
open new windows
The universe is nature's

COSMOLOGY

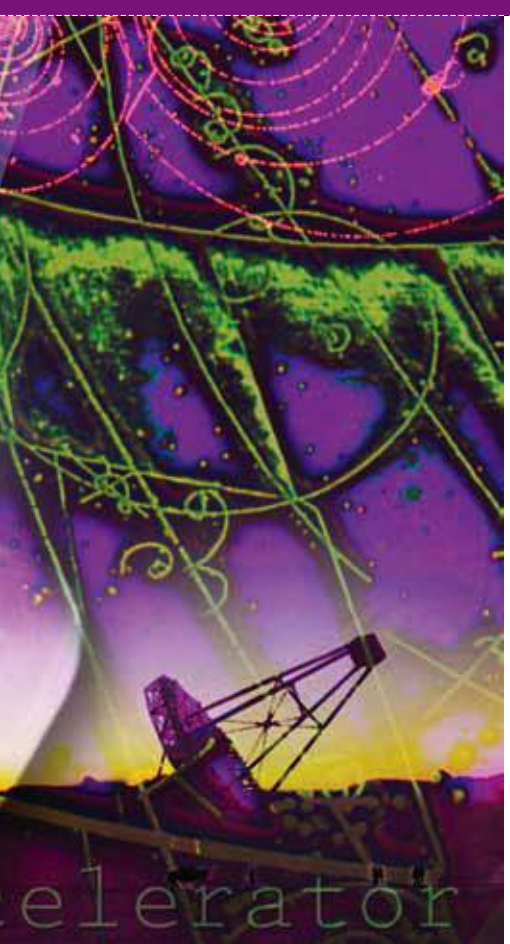
SPECIAL REPORT

in the DETAILS

The smallest particles at the highest energies may hold answers to questions about the universe's most energetic phenomena. /// BY SCOTT WAKELY

Scientists use sophisticated instruments aboard balloons and satellites and on Earth's surface — from Antarctica to Argentina to Arizona — to study energy levels not in existence since moments after the Big Bang. Whether looking at the highest-energy gamma rays above the atmosphere or visible light on Earth's surface, researchers use different methods to answer one of the oldest riddles in astrophysics: Where in the universe do the highest-energy photons and subatomic particles come from? This field, called particle astrophysics, merges the tiny world of particle physics with the large scales of astronomy. Studies in particle astrophysics are moving scientists closer to understanding the universe's earliest moments and most energetic events.

While astronomers use high-redshift (distant) objects to probe conditions in the early universe, particle physicists use ground-based accelerators. By colliding particles of ever-higher energies, physicists are able to produce, for brief instants, energy densities similar to those in the early universe. At these energies, the laws of nature streamline, simplify, and begin to reveal underlying symmetries. The higher the energies, the more fundamental the physics gets, and the closer to the Big Bang scientists probe.



Particle physicists have developed a sophisticated set of tools for measuring high-energy particles and produced the so-called standard model. The model describes virtually all of the particles and interactions we are aware of in nature, but it is incomplete. Questions lurk at the highest energies — energies that are far beyond our ability to recreate on Earth. And so particle astrophysicists look to the sky, to nature's own accelerators, to provide the energies needed to take the next step toward solving these cosmic mysteries.

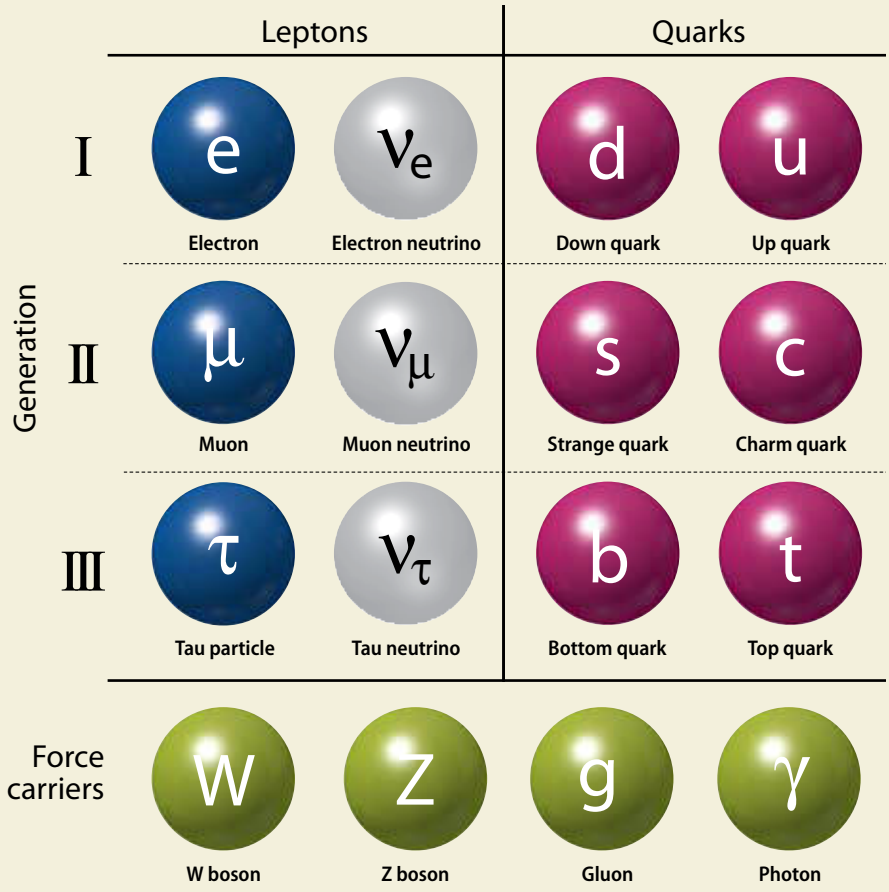
The mystery of disappearing charge

The birth of particle physics can be traced to Europe a century ago. For years, physicists struggled with a riddle: Why did electroscopes (sensitive instruments designed to detect and measure electrical charge) slowly lose their charge?

Scientists knew radiation energetic enough to strip electrons off (ionize) atoms could cause this effect, yet no one had isolated the source of radiation. Was it from radioactivity in natural sources within Earth (as many thought), or was it something else? It was a vexing problem because it occurred even in electroscopes heavily shielded by lead.

HIGH-ENERGY ASTROPHYSICS is an exciting field that links the tiny with the immense. Advances in this area have helped scientists study the universe's earliest moments and most energetic phenomena — and the next few years promise more discoveries. *ASTRONOMY*: KELLIE JAEGER; TELESCOPE ARRAY: VERITAS COLLABORATION; GALAXY: NOAO; BALLOONS: NASA/U. MARYLAND COSMIC RAY PHYSICS LABORATORY, AND TRACER/U. CHICAGO; PARTICLE TRACKS: CERN, FERMILAB, AND BROOKHAVEN NATIONAL LAB

Nature's building blocks



THE STANDARD MODEL summarizes the rules of particle physics. All matter we can see and touch comprises combinations of leptons and quarks. Generation I particles are stable (and were the first group discovered), whereas generations II and III decay. Particles interact by exchanging bosons, the force carriers. These force carriers regulate the strong, weak, and electromagnetic forces, but maybe not gravity. Scientists don't yet have a complete gravitational theory that works at all scales. *ASTRONOMY:* ROEN KELLY

Enter Victor Hess, an intrepid young Austrian physicist from the University of Vienna who tested the ground-based radioactivity hypothesis. Hess took several balloon flights between 1911 and 1913 to measure the rate of electroscope discharge at different altitudes. If the ground was the culprit, then the discharge should have diminished as he climbed.

Hess flew as high as 17,000 feet (5,200 meters) — without breathing equipment. After 10 ascents, he concluded the ionizing radiation initially decreased as his instruments climbed. However, in an unexpected twist, he also found that after this initial drop-off, the ionization rose again — doubling in intensity by 16,000 feet (4,900m).

Hess concluded the results indicated "the penetration of the Earth's atmosphere from outer space by hitherto unknown radiation of exceptionally high penetrating capacity." In other words, the radiation wasn't from the ground — it wasn't even terrestrial. It was cosmic!

The birth of particle physics

Although he didn't know it at the time, Hess had discovered a steady and abundant stream of high-energy extraterrestrial particles impinging on, and interacting with, Earth's atmosphere. The stream — called the cosmic-ray flux — contains atomic nuclei, electrons, positrons, high-energy photons, and more. These cosmic rays were an entirely new source of ionizing radiation. Their discovery precipitated, in the words of Massachusetts Institute of Technology physicist Bruno Rossi, "one of the most extraordinary adventures in the history of science."

The discovery caught the scientific world unprepared. By 1911, the composition of the atom had scarcely been revealed. Nobel laureate Ernest Rutherford had just demonstrated atoms have nuclei, and the entire taxonomy of subatomic particles comprised only the alpha (two protons and two neutrons — the helium nucleus), the beta (a high-energy electron or positron), and gamma rays. It took 25 more years for cosmic-ray physicists, who had been paying increased attention to the details of the cosmic-ray flux, to discover new particles.

The cosmic-ray flux became a laboratory for investigating fundamental physics: Scientists discovered the positron (the electron's antiparticle), the muon, and the pion. The excitement of these discoveries shifted the goal from trying to understand the origin of cosmic radiation to trying to understand its constituents. Enumerating the particles, and describing how they interact with each other, was the new adventure, and it produced the roots of what would become the standard model. Hess received the Nobel Prize in 1936 for his role.

After particle accelerators became common in the 1950s, particle physics as a science diverged from cosmic-ray physics. The accelerator labs could control and monitor particle collisions — particle physicists no longer needed cosmic rays.

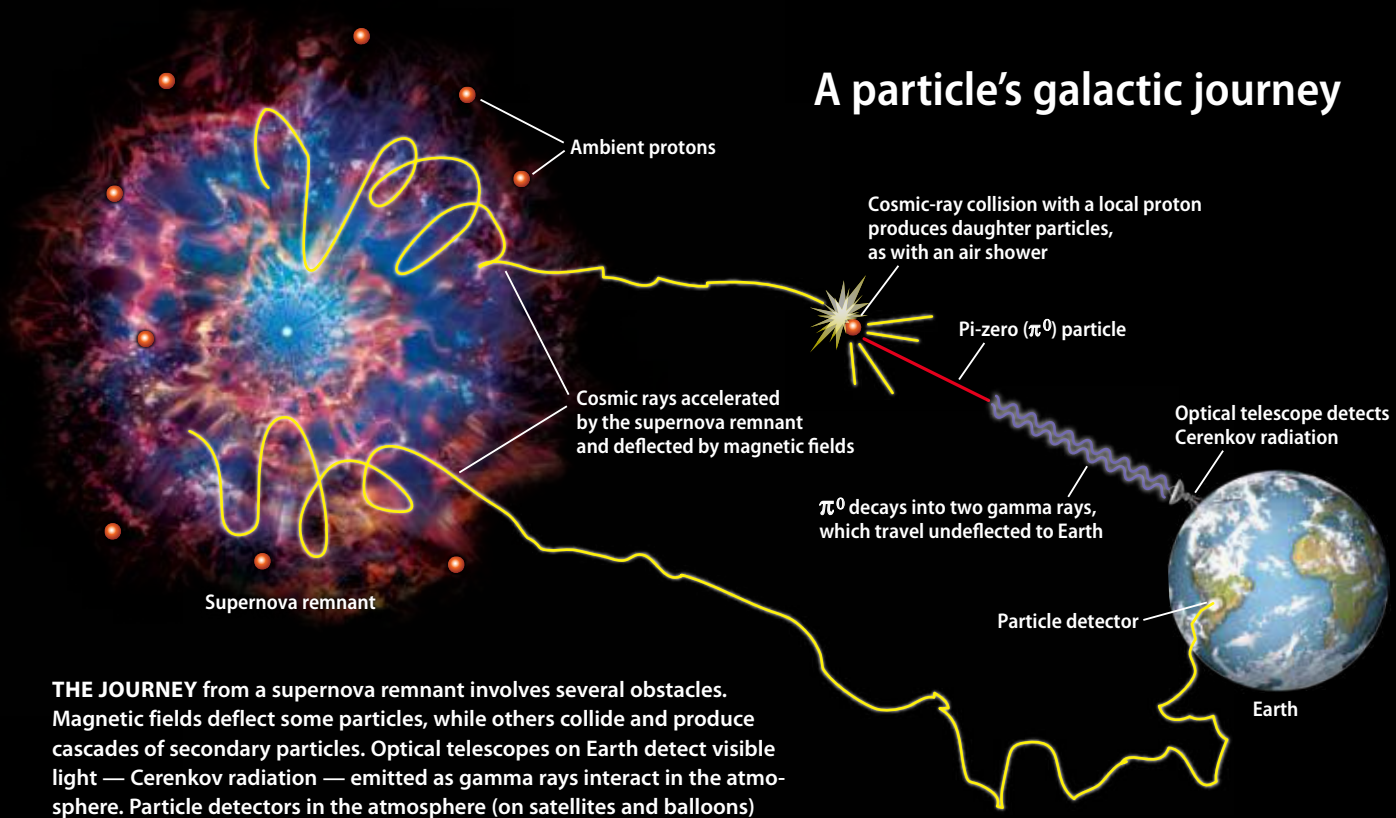
Cosmic rays don't point

Nearly 100 years after Hess' discovery, scientists still do not understand many things about cosmic rays. The exact nature and origin of cosmic rays remain among the longest-standing mysteries in astrophysics.

In addition to possibly having an impact on Earth's weather and climate patterns, cosmic rays fill the galaxy with an energy density equivalent to that of starlight, turbulent gas motion, and even the cosmic microwave background radiation. We can't claim to understand our galaxy if we don't understand cosmic rays.

Cosmic rays contain, more or less, the same ratio of elements we see in our solar system, and they possess energies from around 100 million (10^8) electron volts (eV)

Scott Wakely *is an assistant professor of physics at the University of Chicago. His research involves balloon-borne cosmic-ray instruments, ground-based gamma-ray telescopes, and other detectors.*


A particle's galactic journey
Ambient protons
Cosmic-ray collision with a local proton produces daughter particles, as with an air shower
Pi-zero (π^0) particle
Cosmic rays accelerated by the supernova remnant and deflected by magnetic fields
Optical telescope detects Cerenkov radiation
π^0 decays into two gamma rays, which travel undeflected to Earth
Supernova remnant
Particle detector
Earth

THE JOURNEY from a supernova remnant involves several obstacles. Magnetic fields deflect some particles, while others collide and produce cascades of secondary particles. Optical telescopes on Earth detect visible light — Cerenkov radiation — emitted as gamma rays interact in the atmosphere. Particle detectors in the atmosphere (on satellites and balloons) and on the surface detect higher-energy cosmic rays. *ASTRONOMY: ROEN KELLY*

to more than 100 billion billion (10^{20}) eV. But we still don't know their source. This is especially puzzling for the highest-energy cosmic rays, which can carry energies almost a billion times higher than we can achieve with the best accelerators. What can produce such a remarkable particle?

We can't just collect cosmic rays and trace their trajectories to see where they originate. Most cosmic rays are charged particles, therefore, they are buffeted and deflected as they travel through large-scale magnetic fields. Even in our galaxy's weak magnetic field (roughly 100,000 times weaker than Earth's), a typical cosmic ray's direction is randomized after traveling a few light-years. Only the highest-energy particles can preserve their direction under the influence of these fields.

Supernova connections

Scientists must look for less direct clues to cosmic-ray origins. One method concerns the "power budget" of cosmic rays. Scientists add up the kinetic energy of all of the cosmic rays in the galaxy and then figure out the amount of power it would take to produce them. This is some 10^{42} ergs per second — about 10^{29} megawatts, or a billion times the Sun's total power output. Probably only one event in the galaxy can impart this much power to particles: a supernova.

A supernova's expanding shell of debris can sweep up charged particles and accelerate them to high energies. Only a few supernovae a century would provide the power to generate all of the galaxy's cosmic rays. Furthermore, theoretical models of this acceleration process recreate features scientists have measured in the cosmic-ray flux. Using X-ray satellites, astronomers observe synchrotron emission (radiation emitted when high-energy electrons travel along curved trajectories in magnetic fields) in some supernova remnants (SNRs); this indicates large numbers of very-energetic electrons there. So high-energy electrons, at least, can be made in SNRs. What about nuclei, which make up the bulk of cosmic rays?

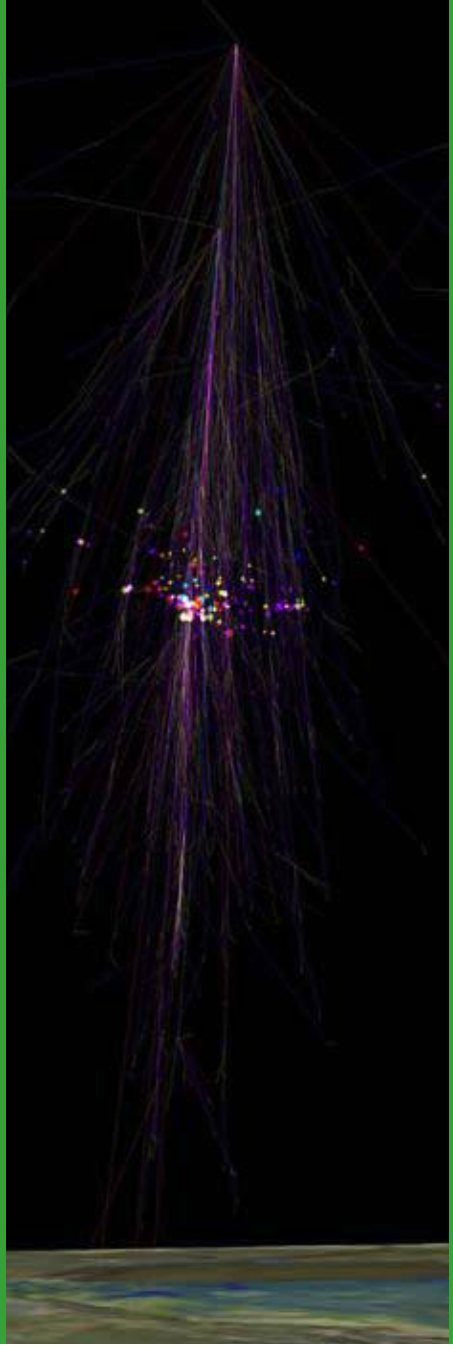
> WE CAN'T CLAIM to understand our galaxy if we don't understand cosmic rays.

The case for them is purely circumstantial. Scientists are searching for clues on how these cosmic rays evolve as a function of energy. For instance, if their composition changes as energy increases, could this point to a specific model of supernova origins?

To answer this question, researchers measure cosmic rays' properties, such as energy and charge. Unfortunately, the number of cosmic rays rapidly dwindles as their energy increases. For every factor-of-10 increase in energy, the number of cosmic rays drops by a factor of 50 to 100 — requiring instruments 50 to 100 times larger.

This wouldn't be a problem if cosmic-ray research could be performed from the ground, but it can't. Earth's atmosphere is an effective shield, preventing primary cosmic rays from reaching the surface. Instead, they are attenuated and absorbed through violent collisions with air nuclei. This leads to cascades of daughter particles called air showers. Hess' discovery, and the subsequent development of particle physics, was based not on the direct detection of cosmic rays, but on the observation of these air showers.

To limit the atmosphere's interference, the most sensitive instruments for measuring cosmic rays are on high-altitude balloons or spacecraft. One of these detectors is the University of Chicago's balloon-borne Transition Radiation Array for Cosmic Energetic Radiation (TRACER) instrument, which, in December 2003, completed a 14-day flight around the South Pole, cruising at roughly 125,000 feet (38,000m).



PARTICLES FROM SPACE

Cosmic rays bombard Earth at a rate of about one particle per square centimeter per second. Primary cosmic rays are 90-percent protons, with electrons, heavier nuclei, and gamma-ray photons making up the rest. Cosmic rays move fast, with velocities near or at the speed of light (any object with mass can't reach light-speed). Therefore, they have high energies ranging from a billion (10^9) to 100 billion billion (10^{20}) eV.

When primary cosmic rays collide with atoms in the atmosphere, the result is a shower of particles — called secondary, or daughter, particles. The initial secondaries are mostly pi-mesons — neutral and charged pions (π^0,π^+, π^-). Neutral pions decay into pairs of gamma rays, which may create an electron (e^-) and a positron (e^+). The charged pions eventually decay into muons (μ) and muon neutrinos (ν_μ). As a result, a large number of electrons, positrons, and muons hits Earth's surface.

Scientists use optical telescopes and pure-water tanks on the surface to detect Cerenkov light emitted when gamma rays and other high-energy particles traverse the atmosphere. They also use detectors on balloons to study these particles in the atmosphere. — *Liz Kruesi*

INCOMING COSMIC RAYS — an alpha particle in this simulation — collide with atoms in Earth's atmosphere, creating a shower of lower-energy particles. The alpha particle creates an array of particles and radiation above the Auger Observatory's Argentina site. Purple corresponds to gamma rays, red to muons, yellow to electrons and positrons, blue to protons, and cyan to neutrinos. COSMUS (UNIVERSITY OF CHICAGO: RANDY LANDSBERG, MARK SUBBARAO, AND DINOJ SURENDRAN)

TRACER uses lightweight detectors to maximize the cosmic-ray collecting area for the equipment's weight. Due to its great size, TRACER can make detailed measurements above energies of 100 trillion (10^{14}) eV, approaching the region where hints from supernova models might appear.

Cosmic tennis balls

At ultrahigh energies, above 10 billion billion (10^{19}) eV or so, the number of cosmic rays falls to less than 1 particle per 0.4 square mile (1 square kilometer) per year. These particles have energies equivalent to well-hit tennis balls; this vastly exceeds what scientists can achieve in the largest accelerator labs. In fact, these energies also outstrip any boost a supernova remnant can deliver — which makes their source more mysterious still.

Measurements are tricky, too, because even the largest balloon or space-based missions wouldn't collect enough particles to be useful. Instead, scientists must use the extensive air showers these particles produce. With a few relatively simple detectors distributed over a large area, scientists can measure multiple aspects of air showers with enough precision to reconstruct some of the properties of the original cosmic rays.

While not as accurate as direct instruments, these detectors can capture the rarest particles because of the large area the equipment covers. One such detector, the Pierre Auger Observatory, is being built in western Argentina. Auger will be the largest scientific instrument in the world. It will cover more than 1,160 square miles (3,000 square kilometers) — roughly the size of Rhode Island — with 1,600 individual detectors each separated by 0.9 mile (1.5 km). Auger may not only track down, for the first time, extragalactic point sources of ultrahigh-energy particles, but it will explore other fundamental physics topics as well.

Supercharged photons

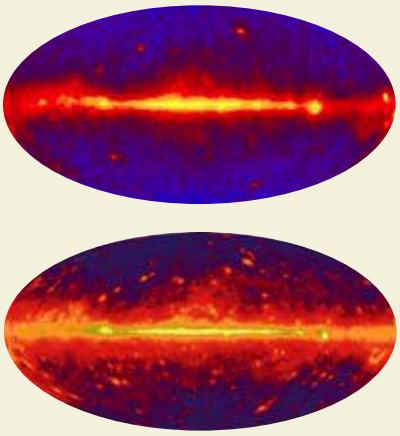
Although gamma rays are less than 1 percent of the total cosmic-ray flux, they have provided some of the most exciting discoveries in particle astrophysics during the last 15 years. Magnetic fields do not alter gamma rays' trajectories, and, therefore, scientists can trace the gamma rays back to their sources. Because the same exotic environments that generate high-energy charged particles can also produce gamma rays, researchers know what to look for when tracking cosmic-ray origins.

In the 1990s, scientists used the Energetic Gamma Ray Experiment Telescope (EGRET) aboard the Compton Gamma Ray Observatory to look at several supernova remnants in our galaxy. Scientists measured the flux of photons with energies of a billion (10^9) eV (or 1 GeV) and found it is consistent, in several cases, with what you'd expect if cosmic rays were being produced in the region. This was an exciting find, but puzzling, because follow-up observations at higher energies found no emission.

In addition, EGRET — while constructing a map of the GeV sky — discovered an entirely new astronomical beast, the so-called gamma-ray blazar. These blazars are a form of active galactic nuclei, objects that researchers know are prolific producers of radiation at other wavelengths. What they didn't know (or even guess) was that blazars can also produce photons beyond 10^9 eV. More remarkable still is the fact that these objects, located hundreds of megaparsecs away, can outshine objects, such as supernovae, in our own galaxy.

EGRET identified more than 65 of these extragalactic gamma-ray emitters.

The EGRET mission ended in 2000, but its legacy will continue with the Gamma-ray Large-Area Space Telescope (GLAST) — NASA's next gamma-ray satellite. Scheduled to launch in August 2007, GLAST will be an order of magnitude larger and more accurate than EGRET.

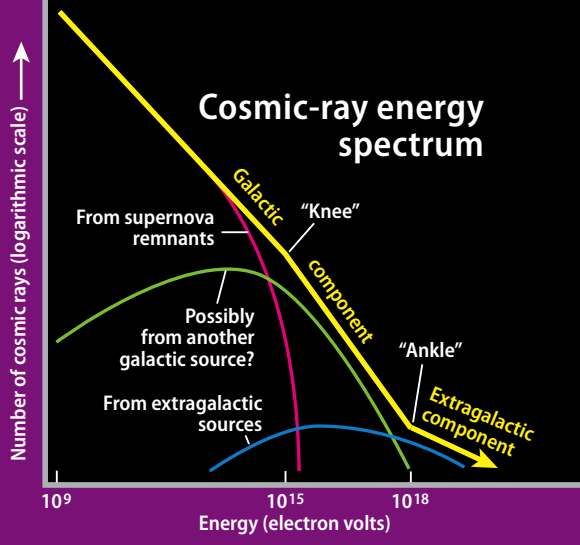


THE GAMMA-RAY SKY as seen by EGRET (top) revealed unknown high-energy sources. The bottom image is a simulated sky map of what GLAST should see when using greater precision. EGRET TEAM/S. W. DIGEL (NASA/GSFC)

WHAT'S THE SOURCE?

The cosmic-ray spectrum is an important tool in particle astrophysics. The yellow line here comes from data. As you look at higher energies, the number of detected cosmic rays drops, but, along the way, there are two kinks: The first is the "knee," and the second is the "ankle." Scientists want to know what causes these kinks.

Cosmic rays above the ankle are from galactic sources. The section above the knee shows cosmic rays created by supernova remnants. Below the ankle, at the highest energies, is the extragalactic component. The area between the knee and the ankle is a possible transition between cosmic rays accelerated by supernova remnants and another source. Scientists aren't sure what causes this kink, or even if it's produced by a different source. More data will answer these questions. — *L. K.*



ASTROPHYSICISTS have observed the energies shown in the yellow line. The three other lines show how suspected sources possibly contribute to the overall signature of cosmic rays. ASTRONOMY: ROEN KELLY

In addition to the potential to discover thousands of new grazars, GLAST will have sensitivity to large-scale annihilations of elementary particles. These particles, not yet seen in accelerator labs, include some of the dark-matter candidates fiercely pursued by scientists, as well as heavy relic particles that may have survived from the Big Bang.

Photons from the edge

As with charged cosmic rays, the frequency of gamma rays declines at higher energies, which makes them difficult to measure. Therefore, ground-based detectors are the only option for making measurements. Once again, Earth's atmosphere interferes by absorbing the original gamma rays and producing air showers.

In the course of these showers, tiny flashes of blue light are emitted. Large optical reflecting telescopes can collect this light — called Cerenkov radiation. The challenge is teasing out the gamma-ray signatures from the overwhelming background of charged-particle showers. In the late 1980s, the Harvard-Smithsonian Center for Astrophysics' Trevor Weekes pioneered a technique to achieve this. As a result, a new form of astronomy has emerged: very-high-energy (VHE) astronomy, which deals with the highest-energy photons known — energies between 10 billion (10^{10}) and 100 trillion (10^{14}) eV.

THE SAME EXOTIC environments that generate high-energy particles can also produce gamma rays.

In 2005, the European collaboration running the High Energy Stereoscopic System (HESS) — named to honor Victor Hess — used Weekes' technique to perform the first high-sensitivity survey of the galactic plane in VHE gamma rays. Using four 12-meter optical reflectors in Namibia, they made a catalog of eight previously unknown gamma-ray sources — two of which hadn't been detected at any wavelength.

Before that discovery, in late 2004, HESS released the first 2-D image of VHE gamma-ray emission from a supernova remnant. The result was a definite gamma-ray signal with virtually all of the characteristics predicted from a cosmic-ray accelerator. Many heralded it as the clinching evidence that solved the mystery of cosmic-ray origins.

Three other VHE gamma-ray observatories are under construction. One effort, led by American, Canadian, Irish, and English scientists, will come online in early 2007 in Arizona. This system, the Very Energetic Radiation-Imaging-Telescope-Array System (VERITAS) will focus the same level of sensitivity on the Northern Hemisphere that HESS focuses on the Southern.

New questions, new tools

Employing techniques perfected in accelerator labs, particle astrophysicists are using charged particles and gamma rays to explore the universe — while addressing fundamental questions. Even neutrino astronomy may be added as a specialty, with several massive installations currently under construction. As for the mystery of cosmic rays: Will the latest VHE gamma-ray results truly resolve this longstanding conundrum? Only time and more data will tell, which is all right. After 100 years, we've learned to be patient.

THE HESS TELESCOPE ARRAY in Namibia has been fully operational since September 2004. In just 2 years, HESS may have answered the cosmic-ray-origin question. HESS COLLABORATION

ONLINE EXTRA Read about particle astrophysics' big year at www.astronomy.com/toc.

BY MARTIN RATCLIFFE AND ALISTER LING

SEPTEMBER 06

The Moon stands front and center

The Moon shoulders a series of superlatives

this month — biggest, lowest, strongest — not to mention taking part in two eclipses. Its egg-shape orbit grooves like a hula dance to a multitude of different beats, some of which fall into step this month. Every 27.55 days, the Moon swings closer to Earth and then loops farther away in an unending cycle of perigees and apogees. This orbital period is a bit out of step with the 29.53 days it takes Luna to go from Full Moon to Full Moon. These two rhythms come into sync September 7, when the Moon scores its second-closest perigee of the year within hours of reaching full phase. This makes it the biggest Full Moon of 2006, 14-percent larger than February's puny fullness. Observers in coastal areas will experience the year's strongest tides.

The Moon's orbit also swings high and low, like the edge of a coin spinning on a tabletop. For those in the Northern Hemisphere, the most obvious effect this summer has been the Full Moon appearing low in the south during the evening. The "Full Moon illusion" — in which the Moon appears bigger near the horizon than it really is — can last for hours because it remains low all evening.

The high/low swing adds to the Harvest Moon effect this month. On nights following a Full Moon near the autumnal equinox, the Moon rises only a few minutes later than the night before, compared with an average of about 50 minutes later at other times of the year. (In 2006, the equinox occurs about midway between the September and October Full Moons.) In the era before floodlights on the combines, farmers used the bonus light from the nearly Full Moon to extend harvesting operations later into the evening. The farther north you live, the stronger the Harvest Moon effect. The table at right gives local daylight times of moonrise for three North American cities. Notice that in Anchorage, the Moon rises earlier with each passing night.

The September 7 Full Moon brings an added treat for observers in Europe, Asia, Africa, and Australia. That night, the Moon passes into Earth's shadow, creating a partial lunar eclipse. At maximum, which occurs at 18h51m Universal Time, 19 percent of the Moon's disk will be immersed in Earth's dark umbral shadow.

The Moon's final event of note comes at new phase September 22, when our celestial neighbor passes directly in front of the Sun. Just as Full Moon occurred near perigee, New Moon comes at apogee, so the Moon isn't big enough to cover the Sun completely. Instead, a ring of sunlight remains visible. Northern South America is the place to be for this annular eclipse, while most of South America and western and southern Africa will see a partial eclipse. For safe-viewing tips, see "Glimpse the great ring of fire" on page 74.

Don't let the Moon hog all your observing time. Uranus reaches opposition September 5, when it glows brightest and appears largest through a telescope. Although the planet is bright enough to glimpse with the naked eye from a dark site, binoculars or a telescope make the task much easier.

Jupiter floats low in the southwest as twilight ends in early September. The giant planet is the brightest evening object except for the Moon. Saturn appears in the east before dawn and gets higher as the month progresses.

Chances are, Jupiter and Saturn will appear blurry when you view them at magnifications above 150x. The problem — they lie low in the sky, so we view them through lots of Earth's atmosphere. Turbulence washes away detail, so be patient, and wait for steady moments.

A RING OF FIRE graces northern South America near sunrise September 22, mimicking this sunset annular eclipse of January 3, 1992.

JOHN AND KATRINA TIPTON

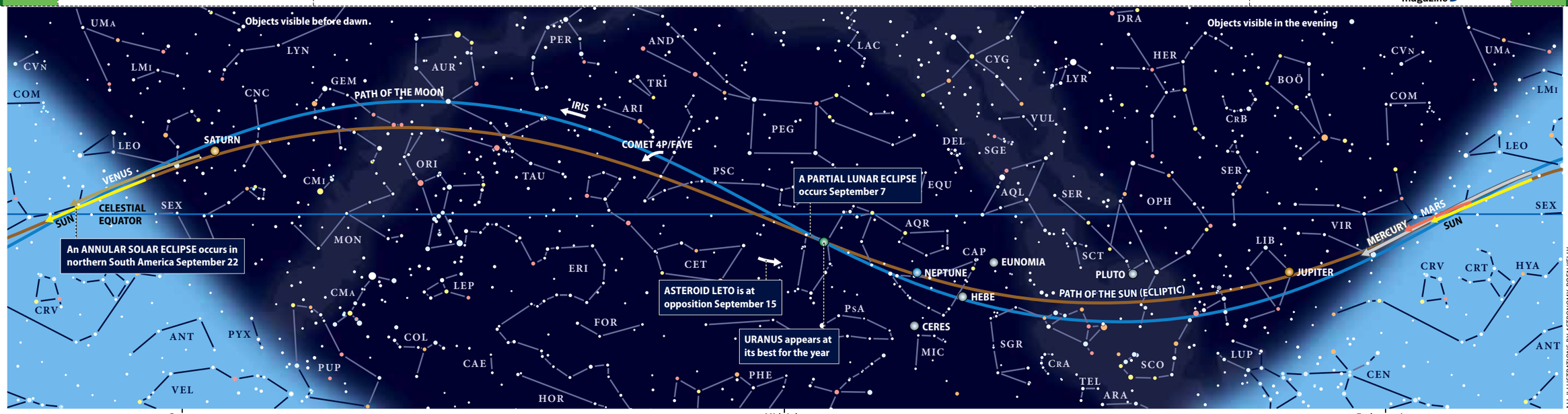
MOONRISE TIMES IN NORTH AMERICA

Date	Chicago	Edmonton	Anchorage
Sept. 7	7:21 P.M.	8:15 P.M.	8:49 P.M.
Sept. 8	7:45 P.M.	8:25 P.M.	8:45 P.M.
Sept. 9	8:09 P.M.	8:35 P.M.	8:42 P.M.

Planets this month

This map unfolds the entire night sky from sunset (at right) until sunrise (at left). Arrows and colored dots show motions and locations of solar system objects during the month.

Astronomy magazine



ALL ILLUSTRATIONS BY *ASTRONOMY*: ROEN KELLY

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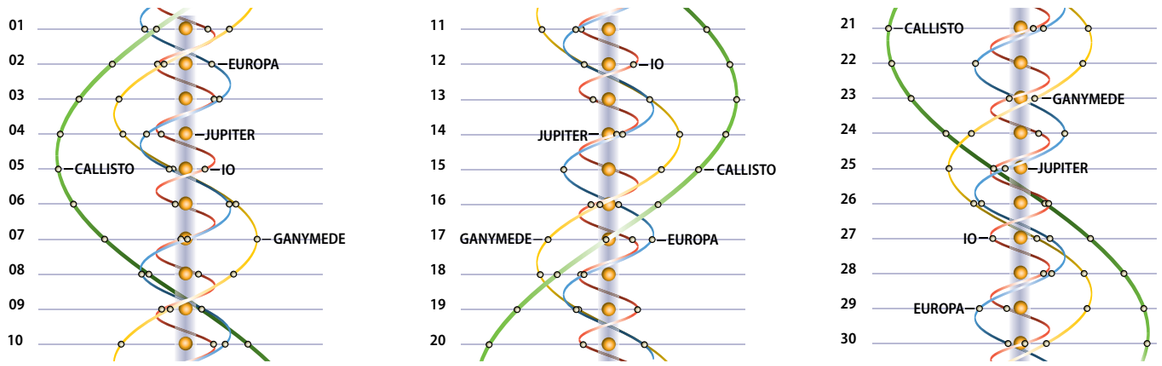
[30] [29] [28] [27] [26] [25] [24] [23] [22] [21] [20]

To locate the Moon in the sky, draw a line from the phase shown for the day straight up to the curved blue line.

PLANETS	MERCURY	MERCURY	VENUS	MARS	JUPITER	SATURN	URANUS	NEPTUNE	PLUTO
Date	September 15	September 30	September 1	September 1	September 15	September 15	September 15	September 15	September 15
Magnitude	−0.9	−0.3	−3.7	1.8	−1.8	0.5	5.7	7.8	13.9
Angular size	4.9"	5.4"	10.1"	3.6"	33.2"	16.6"	3.7"	2.3"	0.1"
Illumination	94%	83%	97%	99%	99%	100%	100%	100%	100%
Distance (AU) from Earth	1.367	1.252	1.645	2.583	5.929	9.988	19.092	29.218	31.118
Distance (AU) from Sun	0.432	0.467	0.718	1.644	5.393	9.155	20.084	30.053	31.170
Right ascension (2000.0)	12h13.9m	13h37.8m	9h44.4m	11h44.0m	14h53.2m	9h28.9m	22h55.9m	21h19.8m	17h35.3m
Declination (2000.0)	−0°48'	−11°25'	14°43'	2°37'	−15°40'	15°47'	−7°42'	−15°49'	−16°02'

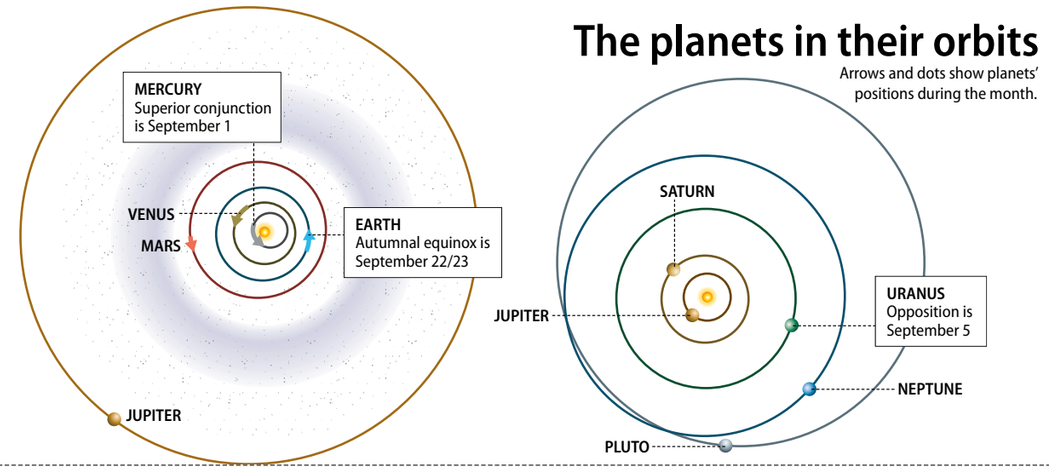
Jupiter's moons

Dots display positions of Galilean satellites at 10 P.M. EDT on date shown. South is at top to match the view through a telescope.



The planets in their orbits

Arrows and dots show planets' positions during the month.



The all-sky map shows how the sky looks at
10 P.M. September 1
9 P.M. September 15
8 P.M. September 30

Planets are shown at midmonth

N

E

W

S

PATH OF THE SUN (ECLIPTIC)

CAMELOPARDALIS
PERSEUS
CASSIOPEIA
CEPHEUS
URSA MAJOR
URSA MINOR
Polaris
DRACO
CANES VENATICI
COMA BERENICES
BOÖTES
Arcturus
Mizar
M51
M81
M82
M31
M33
869
884
ANDROMEDA
TRIANGULUM
PISCES
PEGASUS
LACERTA
CYGNUS
Deneb
Vega
LYRA
M57
HERCULES
M13
CORONA BOREALIS
SERPENS CAPUT
VIRGO
M5
VULPECULA
M27
SAGITTA
Altair
AQUILA
DELPHINUS
M15
Enif
EQUULEUS
OPHIUCHUS
SERPENS CAUDA
SCUTUM
M11
M16
M17
M20
M8
M22
M6
M7
SAGITTARIUS
CORONA AUSTRALIS
SCORPIUS
6231
LUPUS
Antares
M4
LIBRA
JUPITER
CETUS
URANUS
AQUARIUS
CAPRICORNUS
PISCIS AUSTRINUS
Fomalhaut
SCULPTOR
MICROSCOPIUM
GRUS
INDUS
TELESCOPIUM

Magnitudes

Sirius	Open cluster
0.0	Globular cluster
1.0	Diffuse nebula
2.0	Planetary nebula
3.0	Galaxy
4.0	
5.0	

Star colors
The map shows stars' true colors, which depend on surface temperature. Hot stars glow blue; slightly cooler ones, white; intermediate stars (like the Sun), yellow; followed by orange and, ultimately, red. Fainter stars can't excite our eyes' color receptors, and so appear white unless magnified.

How to use this map
This map portrays the sky as seen near 35° north latitude at times shown in the upper left corner of the page. Located just outside the map are the four directions: north, south, east, and west. To find stars above your horizon, hold the map overhead and orient it so a direction label matches the direction you're facing. The stars above the map's horizon now match what's in the sky.

Astronomy magazine

september 06

SUN.	MON.	TUES.	WED.	THURS.	FRI.	SAT.
					[01]	[02]
[03]	[04]	[05]	[06]	[07]	[08]	[09]
[10]	[11]	[12]	[13]	[14]	[15]	[16]
[17]	[18]	[19]	[20]	[21]	[22]	[23]
[24]	[25]	[26]	[27]	[28]	[29]	[30]

ILLUSTRATIONS BY *ASTRONOMY*: ROEN KELLY

01 Mercury is in superior conjunction, 1 A.M. EDT

05 Uranus is at opposition, 7 A.M. EDT

The Moon passes 3° south of Neptune, 6 P.M. EDT

Venus passes 0.8° north of Regulus, 7 P.M. EDT

07 The Moon passes 0.4° south of Uranus, 11 A.M. EDT

Full Moon occurs at 2:42 P.M. EDT; partial lunar eclipse

The Moon is at perigee (221,938 miles from Earth), 11:04 P.M. EDT

10 Asteroid Vesta is in conjunction with the Sun, 9 P.M. EDT

14 Last Quarter Moon occurs at 7:15 A.M. EDT

15 Asteroid Leto is at opposition, 10 P.M. EDT

18 The Moon passes 2° north of Saturn, 11 P.M. EDT

22 The Moon is at apogee (252,587 miles from Earth), 1:20 A.M. EDT

New Moon occurs at 7:45 A.M. EDT; annular solar eclipse

23 Autumnal equinox occurs at 12:03 A.M. EDT

The Moon passes 1.8° south of Mercury, midnight EDT

24 The Moon passes 0.5° south of Spica, 10 A.M. EDT

26 The Moon passes 5° south of Jupiter, noon EDT

27 Mercury passes 1.3° north of Spica, 11 A.M. EDT

28 The Moon passes 0.5° south of Antares, 4 A.M. EDT

30 First Quarter Moon occurs at 7:04 A.M. EDT

ONLINE EXTRA For definitions of terms, visit www.astronomy.com/glossary.

THE DEEP SKY

Catch a high-speed star

Piazzi's flying star

"I have seen the stars move." Wouldn't that be a cool statement to make? Even with a small telescope, you can witness stars moving. We're not talking about the stars' nightly, east-to-west motion caused by Earth's rotation. Rather, we want to see stars move through space. If you choose a fast-moving star, you can detect its displacement relative to more-distant stars in less than a lifetime.

Stars close to Earth appear to move the fastest. Picture two planes: a high-flying jet and a nearby, remote-controlled model. Despite a much slower speed, the model whizzes past your head compared with the stately progress of the distant jet. In the same way, nearby objects offer the best targets for detecting movement. Although Barnard's Star in Ophiuchus moves the fastest, 61 Cygni ranks among the top five.

With your naked eyes, you can see 61 Cygni in the upper left of Cygnus the Swan. A nice surprise awaits you when you point a telescope at 61 Cygni. Not only does it split into a pair of stars, the two components glow with a light-orange hue. From their color and brightness, astronomers deduce these stars are smaller and fainter than the Sun.

The pair takes 653 years to complete one orbit. The stars currently appear 30" apart, a bit less than Jupiter's apparent size. But at a distance of 11.4 light-years, this separation translates into a gap of about 100 astronomical units, or 2.5 times the Sun-Pluto distance.

In 1792 (9 years before he discovered the first asteroid, Ceres), Italian astronomer Giuseppe Piazzi noted 61 Cygni's rapid motion. It moves 5" per year. So, in just 6 years, the pair will move an amount equal to the current space between them. Use as much magnification as the atmosphere and your telescope will allow, and make a sketch of the pair along with nearby stars. Put your finished drawing where you can't lose it. Then, return to the field in 5 or 6 years to see if you notice a change.

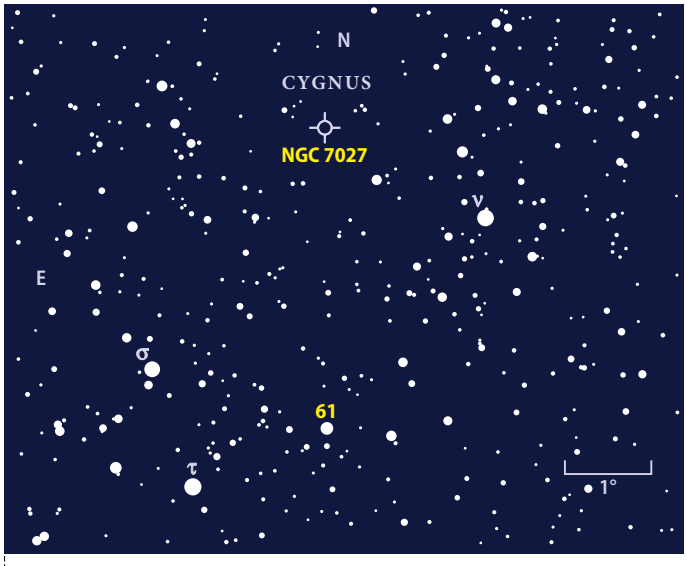
Two hundred years ago, no one knew how far away the stars lay. It wasn't until 1838 that German astronomer Friedrich Bessel finally detected the tiny side-to-side annual wobble of 61 Cygni. This parallax gave Bessel the first rough measure of any star's distance.

Bright blob

If you observe from the city, it helps to target objects with a high surface brightness because they punch through the skyglow. Planetary nebulae are good choices. Although small, their light is concentrated. You can find 8.5-magnitude NGC 7027 a few fields north of 61 Cygni. Unlike the Ring (M57) or Helix (NGC 7293) nebulae, NGC 7027 appears nearly rectangular instead of circular.

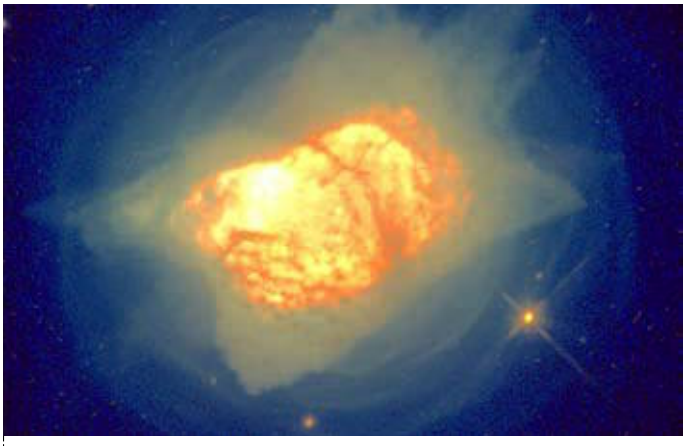
A nebula or high-contrast filter will make NGC 7027 stand out from the background. But, as long as you magnify by at least 100x, you hardly need one. An 8-inch or bigger scope brings out the nebula's green color, although some observers describe it as more blue.

Martin Ratcliffe *is the former president of the International Planetarium Society.* **Alister Ling** *is a meteorologist for Environment Canada.*



ASTRONOMY: THEO COBB

EASTERN CYGNUS OFFERS OBSERVERS
several worthwhile targets, including the rapidly moving double star 61 Cygni and the bright planetary nebula NGC 7027.



BRIGHT PLANETARY NEBULA NGC 7027
looks rectangular through a small telescope, but you won't see the detail the Hubble Space Telescope captured here. H. BOND (STScI)/NASA

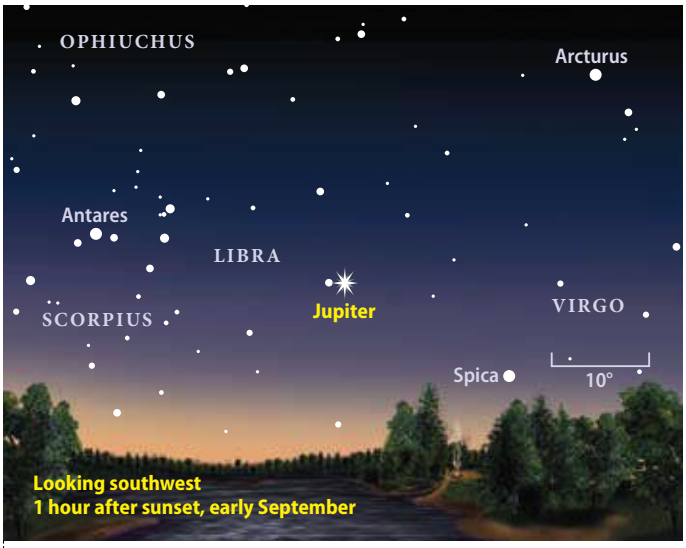
THE PLANETS

View four distant giants

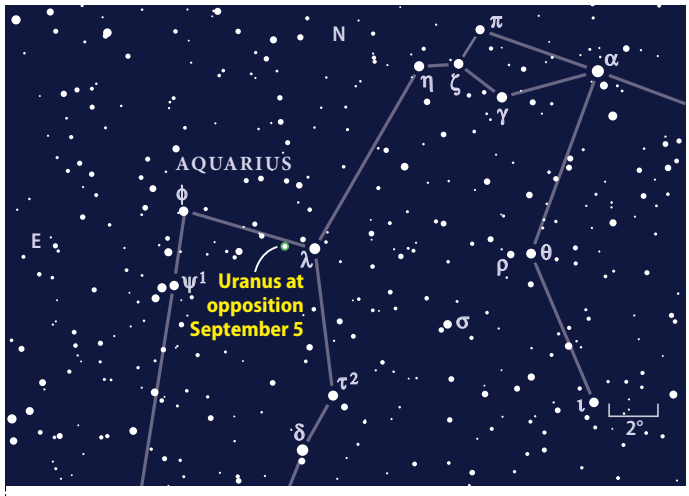
Mercury hugs the western horizon after sunset this month. All of the planets except Pluto lie close to the ecliptic — the apparent path of the Sun across our sky. From the Northern Hemisphere, the ecliptic makes a shallow angle to the western horizon after sunset this time of year, so Mercury can never climb high.

Mercury's greatest elongation east of the Sun comes in October, but the innermost planet appears brighter in late September. On the 27th, Mercury shines at magnitude –0.4 as it passes 1.1° above Virgo's brightest star, 1st-magnitude Spica. You'll need clear skies and an unobstructed horizon to spot the two objects, which set about 40 minutes after the Sun. The Northern Hemisphere's bad luck is reversed south of the equator, where the ecliptic makes a steep angle to the horizon. From there, Mercury and Spica appear 10° high some 40 minutes after sunset.

The most prominent point of light in the evening sky this month is **Jupiter**. The giant planet gleams at magnitude –1.8 low in the southwest after sunset. In early September, Jupiter appears 15° high by the time twilight ends. It sinks lower as the month progresses. This means the best views will come in late twilight. Later in the evening, Jupiter's light passes through thicker layers of Earth's turbulent atmosphere, which smears our view of fine details in Jupiter's own atmosphere. September offers the last good chance to observe the planet until it reappears in the morning sky toward year's end.



JUPITER'S LAST EVENING HURRAH
during 2006 takes place in September; next month, it sinks deep into the twilight glow. *ASTRONOMY:* THEO COBB



ASTRONOMY: THEO COBB

THE GAS-GIANT PLANET URANUS
reaches opposition this month. Sharp-eyed viewers can spot it without optical aid from a dark site.

Jupiter spans 33" and rotates on its axis in less than 10 hours. The rapid rotation and narrow observing window (Jupiter sets about 10 P.M. local daylight time September 1) means you'll be able to see the Great Red Spot only on a few nights. From North America, the Red Spot lies on the visible hemisphere the evenings of September 2, 5, 7, 10, and 12. Although the spot also will be visible later in the month, the planet's low altitude affects the view significantly.

One thing twilight and low altitude won't affect much is the visibility of the four Galilean moons. Io, Europa, Ganymede, and Callisto form a chain of "stars" in line with Jupiter's equator. Because the planet's equator tilts 3.3° to our line of sight, however, the moons don't always line up. As each passes in front of Jupiter, it appears to do so north of the equator. Callisto, the most distant of the four from Jupiter, passes completely above and below the planet's disk.

Observers with 8-inch or larger telescopes can spot **Pluto** after darkness falls. It stands 30° high in the southwest at 9:30 P.M. local daylight time September 1. This leaves about 2 hours to search for Pluto before it dips too low. Later in the month, as this region sinks lower, the observing window shrinks. Throughout September, Pluto lies less than 1° southwest of the 3.5-magnitude star Xi (ξ) Serpentis. This convenient marker will make finding Pluto, which glows dimly at magnitude 13.9, a little less challenging.

Distant **Neptune** reached opposition in August and remains on fine display this month. With the sky darkening

earlier each night, good viewing opportunities arrive earlier each evening. Neptune lies in Capricornus the Sea Goat a bit more than 1° northwest of Iota (ι) Capricorni. This 4.3-magnitude star serves as a useful guide for finding the eighth planet. Iota will be easy to spot in 7x50 binoculars, even if a little haze or street lighting affects your view. You should be able to see 7.8-magnitude Neptune in the same field of view, along with a couple of stars of similar brightness. Neptune will betray its identity within a night or two by virtue of its slow motion relative to the stars. Alternatively, you can confirm which dot is Neptune by swinging your scope to the planet. Neptune shows a 2.3"-diameter disk with subtle blue-gray shading.

Neptune's cousin, **Uranus**, lies one constellation farther east, in Aquarius the Waterbearer. Uranus reaches opposition September 5, when it rises at sunset, climbs highest in the south around midnight, and sets at dawn. Glowing at magnitude 5.7, it's an easy target through binoculars and shows up even to the naked eye from a dark site.

Uranus begins September 1.4° east of 3.7-magnitude Lambda (λ) Aquarii, and it ends the month just one Moon-width (0.5°) away. Watch its westward motion relative to Lambda from night to night. Uranus is moving "retrograde" — in the opposite direction from normal — because Earth is overtaking the outer planet and passing it due to our faster orbit. A small telescope will show the planet's 3.7"-diameter disk, which glows with a distinct blue-green hue.

You'll have to wait nearly until dawn to see the next planet rise. **Saturn** returns to the morning sky in September and climbs higher with each passing day. Unlike planets in the evening sky, morning planets this time of year benefit because the ecliptic makes a steep angle to the eastern horizon before dawn.

ASTRONOMY: THEO COBB

SATURN RETURNS TO PROMINENCE

in the morning sky this month, rising well before the Sun and shining brightly among the background stars of Leo.

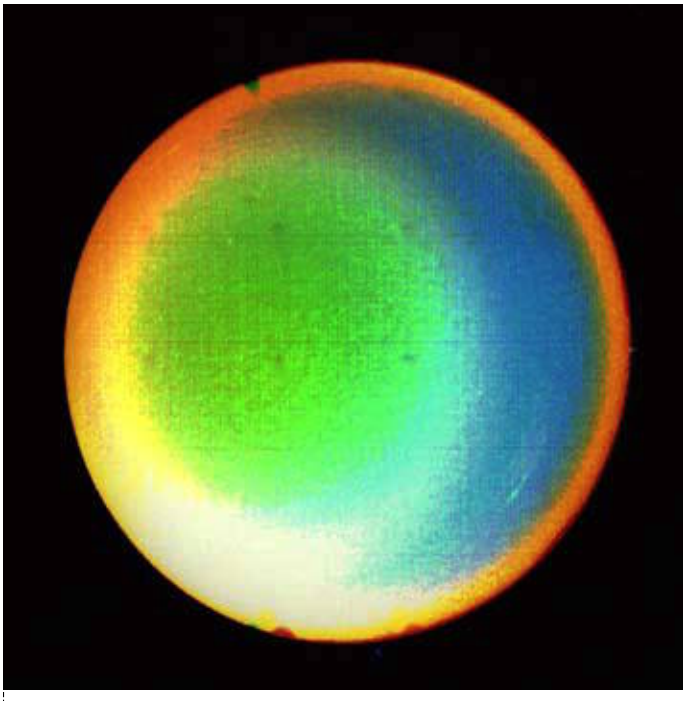
Saturn rises early enough during the second half of September to give nice views in a dark sky. The ringed planet shines at magnitude 0.5 and shows a disk 17" in diameter. The magnificent rings span 38". Saturn lies in Leo the Lion and moves slowly eastward from night to night, heading in the direction of Leo's brightest star, 1st-magnitude Regulus. By September 30, Saturn lies 8° west-northwest of Regulus.

A smiling crescent Moon stands 9° above Saturn September 18 and sits just 4° below Saturn the next morning. A telescope at low power delivers wonderful views of the crescent Moon. Combine this with the magnificent sight of Saturn and its rings, and you'll get the day off to an excellent start.

On September 1, Saturn lies 6° from Venus. **Venus** then shines at magnitude –3.7 and, through a telescope, shows an almost fully illuminated disk just 10" in diameter. The sight of Venus near full phase was unknown before Galileo turned his new telescope to the sky in 1610. This simple observation proved profound because it supported Copernicus' Sun-centered solar system and contradicted Ptolemy's prevailing Earth-centered one. A fully lit Venus simply couldn't exist in the Ptolemaic system. An even more profound realization wrought by Galileo's studies was that observation can guide our ideas about the universe. This idea remains a foundation of modern science.

Venus will disappear from view by the end of September as it prepares to round the Sun. On September 5 and 6, Venus lies close to Regulus, passing 1.1° north of the star the first morning and moving to its east the following morning.

A thin crescent Moon sits 1° to Venus' right September 21, almost exactly 24 hours prior to New Moon. Spying this old Moon will be a challenge, requiring atmospheric clarity and an unobstructed eastern horizon.



URANUS SPORTS A BLUE-GREEN GLOW

when seen through a small telescope, but don't expect to see the atmospheric detail Voyager 2 saw. NASA/JPL

METEORS AND MOONS

Can you spot an ancient Moon?

Sporadic or not?

September nights offer a nearly unparalleled view of sporadic meteors. These apparently random bits of dust burn up in a blaze of glory when they strike our atmosphere at a few dozen miles per second. Most get incinerated at an altitude of 50–70 miles.

Part of what makes September a good month for viewing sporadic meteors is the dearth of major meteor showers. This month provides a few minor showers, however, with the Alpha Aurigids probably at the top of the list. This shower peaks the morning of September 1, when observers at dark sites can expect to see roughly 7 meteors per hour, matching the sporadic rate.

How can you tell a shower meteor from a sporadic? The Alpha Aurigids all arrive from the same direction in space. These meteors appear to radiate from a point near the bright star Alpha Aurigae (better known as Capella), hence the shower's name. Sporadics, on the other hand, come from random directions.

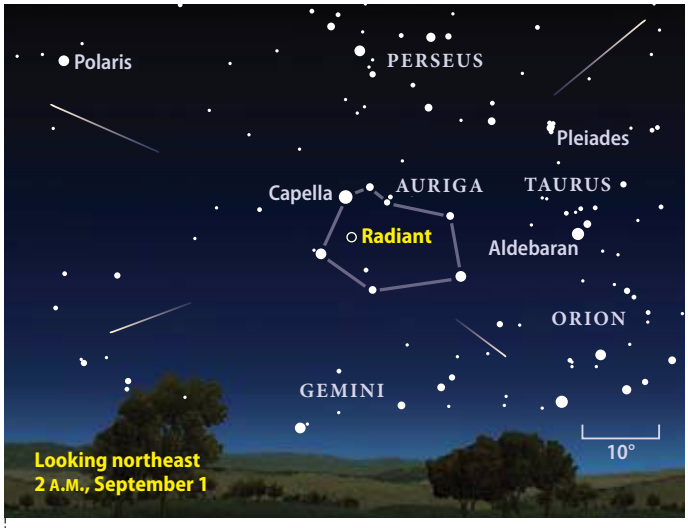
The best time to view the Alpha Aurigid shower is after midnight, when we're on Earth's leading hemisphere as we orbit the Sun. Auriga lies high in the early morning sky, and the First Quarter Moon sets around midnight. A secondary shower — the Delta Aurigids — peaks September 9, but the Moon is then just past full, and viewing will be difficult.

Spy an old Moon

Seeing the Moon within a day or so of its new phase is a challenge that many backyard observers embrace. Viewing a slender crescent set against a multi-hued twilight sky is a sight not soon forgotten. Timing is critical for such views, and opportunities don't arise every month at every location. The Moon must reach new phase approximately 24 hours before an evening sighting or 24 hours after a morning sighting, and it must be more than a degree or two high. Clear skies and a flat, unobstructed horizon also prove invaluable.

North American observers have a good chance this month to see an old Moon, and a bright object lies nearby to guide them. Part of the reason for the favorable circumstances is the nearly vertical angle the ecliptic makes to the eastern horizon on mornings this time of year. Essentially all of the Moon's angular distance from the Sun translates into altitude above the horizon.

For observers in the Midwest, the Moon is 24 hours from new phase the morning of September 21. Venus, which shines at magnitude –3.8 and is easier to see, lies just 1° away then. Grab your binoculars, and carefully scan the region just to Venus' right. Observers farther east will see the Moon an hour earlier; on the West Coast, the Moon will be 22 hours from new this morning. Venus rises about 50 minutes before the Sun, and the sky will brighten quickly. Of course, lucky observers in South America and western and southern Africa have a chance to see the actual New Moon a day later, when it appears in silhouette against the Sun's face during an annular solar eclipse.



ASTRONOMY: THEO COBB

THE ALPHA AURIGID METEOR SHOWER
boasts around 7 meteors per hour at its peak September 1, when the Moon will be gone from the morning sky.

A THIN CRESCENT MOON HANGS LOW
in the east before dawn September 21, imitating this 27-hour-old Moon seen June 7, 2005. LOUIS MARCHESI

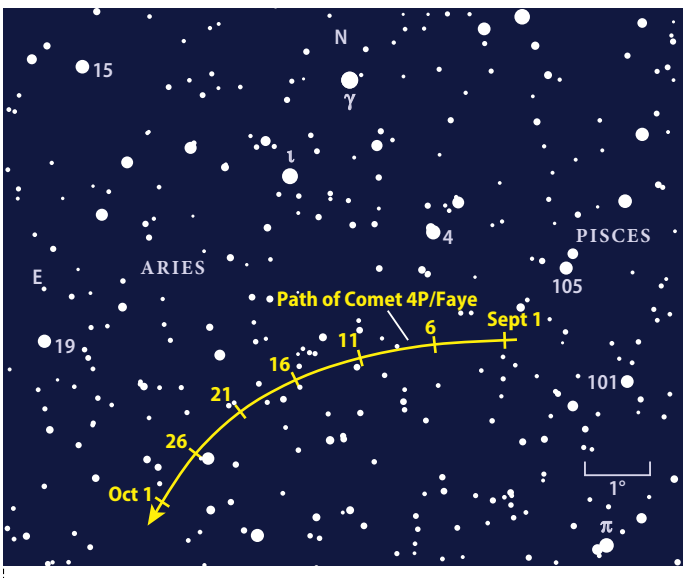
Comet Faye brightens for binoculars

Faye leads the way

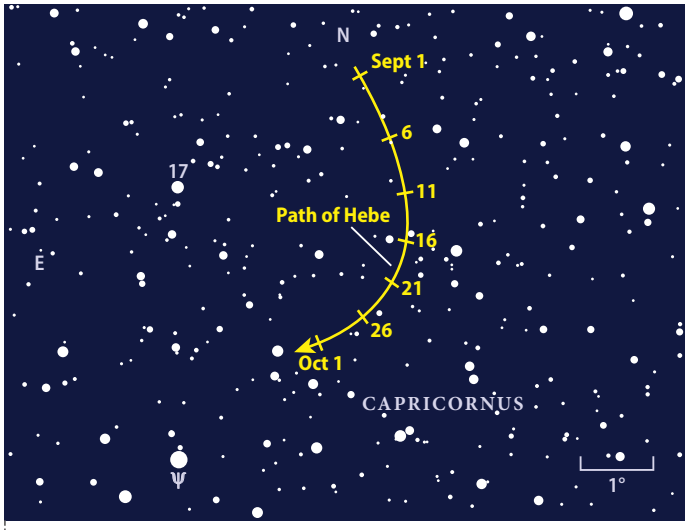
Barring an unexpected newcomer, autumn's brightest comet will be 4P/Faye. It continues to brighten this month, when it should glow around 9th magnitude. Through a small scope, Faye should appear reminiscent of the fainter galaxies in the Messier catalog.

Although the comet may look similar to a distant elliptical galaxy, it couldn't be more different in reality. Comets are small objects, only a mile or so across, surrounded by a halo of dust particles that can reach a million miles in diameter. The dust reflects sunlight, giving the comet an amorphous glow. A large galaxy, on the other hand, can span 100,000 light-years or more.

The 4P in 4P/Faye's name means it was the fourth periodic comet to have its orbit determined, after comets 1P/Halley, 2P/Encke, and 3D/Biela. You may not recognize the name Biela because the comet disintegrated and was last seen in 1852, suffering a fate similar to Comet 73P/Schwassmann-Wachmann 3's a few months ago. Faye has a period of 7.5 years and always stays beyond the orbit of Mars. On every second return, the comet lies on the far side of the Sun from Earth, so we can't see it.



COMET FAYE REACHES 9TH MAGNITUDE
in September as it slowly moves through southern Aries and climbs high in the morning sky. *ASTRONOMY:* THEO COBB



ASTRONOMY: THEO COBB

HEBE TREKS THROUGH CAPRICORNUS
this month. Telescope owners should have little trouble tracking this 8.5-magnitude asteroid during the evening hours.

Generally speaking, comets appear diffuse, and their brightness spreads over a large area. This means a 9th-magnitude comet appears significantly fainter than a 9th-magnitude star. Comet Faye climbs reasonably high by midnight, so your best views will come in the last 10 days of September, when moonlight doesn't add to the skyglow. Faye lies in Aries the Ram about 5° south of the nice double star Gamma (γ) Arietis.

A night cap

As twilight fades on September evenings, the constellation Capricornus the Sea Goat crosses the meridian and appears due south. Also called a "transit," this position marks the moment when an object appears highest in the sky and has climbed farthest above the worst atmospheric haze and turbulence.

Asteroid 6 Hebe lies in southwestern Capricornus and will be fairly easy to track with a small telescope. It currently glows around magnitude 8.5, and only three stars brighter than Hebe occupy this sector of space. On the night of September 15, Hebe slides between two of these stars, each a magnitude brighter than the asteroid.

The first asteroids were discovered in the early 1800s. Populating the zone between Mars and Jupiter, these rocky objects were given numbers in the order they were found. They also received names, usually of gods and goddesses deemed less important than those honoring the planets. In Greek mythology, Hebe is the daughter of Zeus and Hera and embodies youth and grace.

Faster than a speeding

Superman would be hard-pressed to match the speed of most objects in space. /// BY RICHARD TALCOTT; ILLUSTRATION BY ROEN KELLY

How fast do we move through space? It's a question that comes up frequently, from schoolkids first learning about the universe to curious adults wanting to know our place in the cosmos. Unfortunately, there's no easy answer.

Centuries ago, when most people believed Earth was stationary at the center of the universe, the answer couldn't have been simpler. But today, astronomers recognize Earth — and every object, for that matter — moves in many ways. Earth rotates on its axis, at a rate that depends on latitude; it revolves around the Sun, at a pace governed by its distance; and it circles our galaxy's center along with the Sun. To top it off, the Milky Way Galaxy moves relative to every other galaxy.

All of the quoted speeds on these pages are in miles per hour (mph) for relatively slow motions, or miles per second (mps). To convert these values to kilometers per hour or second, multiply by 1.61.

NEPTUNE
orbital speed: 12,253 mph
rotational speed: 6,001 mph

URANUS
orbital speed: 15,290 mph
rotational speed: 5,788 mph

PLUTO
orbital speed: 10,620 mph
rotational speed: 30.4 mph

EARTH
orbital speed: 66,629 mph
rotational speed: 1,040 mph

SATURN
orbital speed: 21,614 mph
rotational speed: 22,994 mph

PERSON
brisk walk:
4 mph

AUTOMOBILE
interstate speed:
65 mph

COMMERCIAL JET
cruising speed:
600 mph

JUPITER
orbital speed:
29,236 mph
rotational speed:
28,361 mph

VENUS
orbital speed: 78,341 mph
rotational speed: 4.1 mph

MARS
orbital speed: 53,979 mph
rotational speed: 539 mph

MERCURY
orbital speed: 107,088 mph
rotational speed: 6.8 mph

SUN
rotational speed: 2,231 mph

COMET 1P/HALLEY (PERIHELION)
orbital speed: 122,070 mph

SUN
orbital speed: 135 mps
(486,000 mph)

Our solar system

Orbital speed depends on an object's distance from the Sun, with closer objects moving faster. Likewise, an individual object moves faster when nearer the Sun. The values here are averages. Rotational velocity is given for an object's equator, where the speed peaks.

Astronomy magazine

bullet

COMET 1P/HALLEY (APHELION)
orbital speed: 2,039 mph

Cosmic Microwave Background

The most distant observable radiation is the fading glow from the Big Bang itself. Located all around us at a distance of 13.7 billion light-years, this radiation is moving away from us at nearly the speed of light. NASA/WMAP

ROBERT LUPTON AND SDSSC

Coma cluster

The Coma cluster contains more than 10,000 galaxies, spans 10 million light-years, and lies roughly 350 million light-years from Earth. The expansion of the universe is carrying it away from the Sun at 4,400 mps (16,000,000 mph).

CFHTJ.-C. CUILLANDRE/*CQELUM*

Virgo cluster

The closest large galaxy cluster to us lies some 50 million light-years away in the constellation Virgo. Although the thousands of galaxies there have a range of recessional velocities, the giant elliptical M84, near the cluster's core, is about average, with a speed of 659 mps (2,370,000 mph).

Andromeda Galaxy (M31)

The nearest large galaxy to the Milky Way and the largest member of the Local Group, M31 is approaching the center of our galaxy at 62 mps (220,000 mph). Because the Sun's orbit around the Milky Way's center currently is toward M31, our approach velocity is 186 mps (670,000 mph). JASON WARE

Milky Way

The visible disk of our galaxy spans about 100,000 light-years, and the Sun lies about halfway from the nucleus to the edge.

Light The cosmic speed limit is the speed of light in a vacuum: 186,282 mps.

astronomics™ . . . our 28th year.

The optical center of the known Universe.™

We've been helping people choose the right telescope since 1979. We have the experience (a staff total of over 150 years of experience using and selling telescopes) to help *you* pick the telescope that fits your needs (and your budget). And, with our seven-figure inventory, we can usually ship you the right scope, right away, from the hundreds of scopes we stock.

We started ***astronomics*** over 26 years ago because we loved astronomy,

21st century Celestron go-to . . . at a 1984 price.

If you fondly remember the original orange-tube Celestron C8 – the scope that made serious astronomy affordable – the **Celestron NexStar 8i Special Edition** will bring back the good old days . . . at a low price straight out of the 1980s!

The scope – finished in Celestron's vintage orange and black – includes a sophisticated go-to computer with the latest no-guesswork *SkyAlign* technology, and the bright images of Celestron's best-ever Starbright XLT multicoatings.

The amazing part? This feature-loaded 21st century telescope is available for less than the price of a C8 from 1984 that didn't even have a computer.

Telescopes have come a long way over the past 22 years. But the performance and value of a Celestron have always been standards you can rely on.

Celestron 8" f/10 N8iSE

Get a free electronic eyepiece with the $499 Coronado PST solar telescope.

$499

Coronado's solar scope shows you the constantly changing drama of solar flares and prominences leaping off the Sun. At only $499, it's a world-class value.

The **Coronado PST** (Personal Solar Telescope) doesn't just show you sunspots, like an ordinary solar filter. It shows you the violent face of the living Sun. It includes a 60mm refractor, built-in sub-Ångstrom solar filter, a safe Sun finder, and a 25mm eyepiece.

And now, while quantities last, buy a Coronado PST at its regular price, and you get a Meade electronic eyepiece for free! The $149 list price electronic eyepiece lets you put those fascinating monochrome PST solar images on a TV screen for all to see.

Celestron NexImage captures the solar system for $99.

The $99 **Celestron NexImage** CCD camera takes high power full color images of the Moon and planets with any telescope. It sends them to your computer to view live or print out later. The full color CCD imaging chip in the NexImage has a big 640 x 480 array of 5.4 micron pixels for sharp and clear high-resolution images.

For wider lunar panoramas, the optional $24.50 NexImage Reducer Lens doubles the camera's field of view.

> My first experience with your company was a most pleasant one. I ordered a scope by phone and received it in good condition. The sales person was helpful, knowledgeable, and cheerful. You can expect additional orders shortly. Nice job on the website!
>
> **Customer Quote of the Month #174**

Not much money buys you a lot of Konus.

The low prices of **Konus** telescopes are downright amazing.

If you're not looking for go-to, but just want a good scope for casual observing, consider this optically nice 90mm (3.5") **Konusmotor-90** f/11 refractor. It has an equatorial mount with adjustable tripod, a 6 x 30mm finderscope, battery-powered motor drive so you can use it anywhere, and *two* 1.25" Plössl eyepieces.

We sell it by the dozens because it's a great value at $209. And there are other Konus motor drive scopes from $109 to $799.

3.5" f/11 Konus refractor

Want 1000s of *unbiased* equipment reviews? www.cloudynights.com

A better star diagonal makes any scope better. Astro-Tech *dielectric* diagonals from $69.95 *are* better.

A good mirror star diagonal increases light transmission *and* improves planetary contrast and detail when compared with the so-so prism diagonal supplied with most scopes.

Astro-Tech diagonals are *really* good diagonals. Choose from 96% reflectivity enhanced aluminum or 99% reflectivity *46-layer dielectric* mirror coatings, each on a 1/10th wave BK7 optical glass substrate. Each has a non-marring brass compression ring eyepiece holder. The 2" diagonals also come with a 1.25" eyepiece adapter with a compression ring eyepiece holder at no extra charge. The 2" diagonals are available with your choice of a standard 2" barrel to use in a refractor or with a threaded ring that connects to a Schmidt-Cassegrain rear cell.

Here are the five top-quality **Astro-Tech** star diagonals that we keep in stock:

1.25" dielectric	**$69.95**
2" enhanced aluminum	**79.95**
2" SCT enhanced aluminum	**89.95**
2" dielectric	**139.95**
2" SCT dielectric	**149.95**

The only thing better than getting a TeleVue is getting your TeleVue right away.

When you get the urge for a TeleVue, you usually want it right away. You don't want to wait until your dealer gets around to ordering it.

You rarely have to wait for a TeleVue from ***astronomics***, because *we keep a six-figure TeleVue inventory in stock.*

Here are a few of the TeleVue basic refractor optical tubes that we stock.

TV-60, 2.4" f/6 apo	**$825.00**
TV-76, 3" f/6.3 apo	**1320.00**
TV-85, 3.35" f/7 apo	**1750.00**
TV-102, 4" f/8.6 apo	**2250.00**

And the new photo/visual *imaging system* refractors are in stock in limited supply. They include a larger non-vignetting focuser, Focusmate, photo accessory adapter, carrying case, and more.

TV-60is, 2.4" f/6 apo	**$1695.00**
TV-102iis, 4" f/8.6 apo	**2985.00**
NP-101is, 4" f/5.4 Petzval apo	**3985.00**
NP-127is, 5" f/5.2 Petzval apo	**6985.00**

Need an eyepiece? Here are just a few of the TeleVues we can ship today.

8, 11, or 15mm 1.25" Plössl	**$85.00**
3, 4, 5, 6, 8, 10, 12, 14, or 18mm 1.25" Radian	**250.00**
2.5, 3.5, 5, 7, 9, 11, or 13mm 1.25" Nagler Type 6	**290.00**

$14,000 for a 10" Ritchey-Chrétien optical tube only? A Meade 10" R-C *with mount* is only $3399!

The optical tubes made by the best-known Ritchey-Chrétien specialist cost $14,000 to $34,000. And many savvy astronomers think those hand-crafted gems are well worth the high cost.

But not everyone can afford to fork over the price of a new car to get an optical tube – and still have to pay an arm and a leg for a mount to hold it. For these astronomers, Meade has developed the new **Meade LX200R** scopes. These use f/10 versions of the modified Ritchey-Chrétien optics used in Meade's famous RCX400 scopes, and the same superb go-to mounts as Meade's best-selling LX200GPS series. The result is state-of-the-art R-C telescopes at prices within reach and reason.

The 8" to 14" scopes below usually ship from our stock (saving you the sales tax if you live in California).

Meade 8" f/10 LX200R
$2499
freight paid

Here are the *freight-paid* prices on the LX200R scopes that we ship from our stock:

8" **LX200R**	**$2499.00**
8" **LX200R,** with UHTC optics	**2674.00**
10" **LX200R**	**3399.00**
10" **LX200R,** with UHTC optics	**3634.00**
12" **LX200R**	**4399.00**
12" **LX200R,** with UHTC optics	**4694.00**
14" **LX200R**	**$5999.00**
14" **LX200R,** with UHTC optics	**6349.00**

Because of their weight, these 16" LX200R scopes ship to you via truck from Meade.

16" **LX200R,** without mount, w/UHTC	**11,529.00**
16" **LX200R,** tripod, w/UHTC	**12,494.00**
16" **LX200R,** altaz pier, w/UHTC	**12,524.00**
16" **LX200R,** eq pier, w/UHTC	**12,779.00**

Get a free electronic eyepiece with a Meade ETX.

While quantities last, buy a **Meade ETX Maksutov-Cassegrain** go-to and get a *free* Meade electronic eyepiece!

The $149 list monochrome electronic eyepiece lets you record close-up lunar and planetary images on a camcorder to view later or you can put them on a TV screen for all to see in real time. It's great for viewing with family and friends.

Meade ETX go-to scopes start at $599 and make it easy to find your way around the sky. Once you tell it where you are on earth, the date, and the time, your scope moves by itself to two alignment stars. Make sure the scope's finder is centered on those stars. Then tell your ETX which of the more than 30,000 objects in its memory you want to see, and your scope takes you to see that object *automatically.*

Each ETX comes with all you need to start observing – full length tripod, finder, 26mm Super Plössl eyepiece, and more.

ETX-90PE
$699
freight paid

And now, while quantities last, that "more" also includes a very useful free Meade electronic eyepiece!

Celestron *SkyAlign* go-to scopes start at a low $279.

You don't need to know the Pleiades from Polaris to find your way around the sky with a **Celestron SLT** go-to scope. With Celestron *SkyAlign* technology, just point your SLT at any three of the 50 brightest lights in the sky (3 stars, or 2 stars and a planet), and the SLT will find the planets and over 4,000 deep space objects for you *automatically.* A few anonymous points of light are all you need to find your way around the skies.

80mm Celestron NexStar 80 SLT

Celestron SLT no-guesswork go-to scopes are available in these sizes:

NexStar 60, 60mm refractor	**$279.00**
NexStar 80, 80mm refractor	**379.00**
NexStar 102, 102mm refractor	**479.00**
NexStar 114, 114mm reflector	**399.00**
NexStar 130, 130mm reflector	**439.00**

Each has *two* eyepieces, red dot finder, motor drives, stainless steel tripod, NexStar computer, software to control the scope from your computer, and more.

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Anyone can sell you a telescope. We'll sell you the right telescope.™

not just as a business. Our sales may have grown over a thousand-fold since that first year, but we're still the same family-owned, family-run, full-line telescope dealer we were in 1979. And we still love astronomy.

30 good grab-and-go scopes under 80mm.

Compact fast focal ratio refractors in the 60mm to 80mm aperture range have become all the rage lately as the prices of premium achromatic and apochromatic (color-free) optics have dropped to affordable levels.

People are finding that a high quality compact grab-and-go scope that mounts on an ordinary camera tripod is ideal to take out into the back-yard for spur-of-the-moment stargazing. It's also great for nature studies and as a convenient travel scope or vacation take-along.

Left to right: **Astro-Tech** AT66ED, $329; AT80, $379; AT80ED, $529

We have grab-and-go scopes available from A to Z – from Astro-Tech to ZenithStar – at prices that fit all budgets.

Counting all of the color choices available, we keep 30 different 60mm to 80mm grab-and-go scope models in stock from seven different manufacturers. And that's a lot of good glass! Just take a look at the selection of scopes we have available:

Astro-Tech AT-66ED: 66mm f/6 ED apochromat, rotating dual-speed Crayford focuser, choice of eight colors, equatorial dovetail, hard case ..... **$329**^{00}

Astro-Tech AT-80: 80mm f/6 achromat, rotating dual-speed Crayford focuser, choice of four colors, soft case ..... **379**^{00}

Astro-Tech AT-80ED: 80mm f/6.9 ED apochromat, rotating dual-speed Crayford focuser, choice of two colors, equatorial dovetail, hard case ..... **529**^{00}

Celestron 80ED: 80mm f/7.5 ED optics, 6 x 30mm finder, rack and pinion focuser, 25mm Plössl eyepiece, image-erecting diagonal, equatorial dovetail ..... **409**^{95}

Celestron Onyx: 80mm f/6.25 ED optics, rotating Crayford focuser, peep-sight finder, equatorial dovetail, hard case ..... **699**^{00}

Meade 80mm ED Triplet: 80mm f/6 ED triplet apochromat, adjustable lens cell, Crayford focuser, hard case ..... **599**^{00}

Meade 80mm ED Triplet package: 80mm f/6 ED triplet apochromat, adjustable lens cell, Crayford focuser, 2" dielectric diagonal, hard case ..... **699**^{00}

Takahashi FS-60C: 60mm f/5.9 fluorite apo, rack and pinion focuser ..... **829**^{00}

TeleVue TV-60: 60mm f/6 SD apochromat, two-stage focuser (drawtube plus helical fine focus), soft case ..... **825**^{00}

TeleVue TV-76: 76mm f/6.3 SD apochromat, rack and pinion focuser, choice of two colors, soft case ..... **1320**^{00}

TeleVue TV-76 package: 76mm f/6.3 SD apochromat, rack and pinion, 20mm Plössl, 2" Everbrite diagonal, choice of two colors, soft case ..... **1725**^{00}

Vixen A80SSWT: 80mm f/5 achromat, rack and pinion focuser, flip mirror 1.25" diagonal, red dot finder, equatorial dovetail ..... **399**^{00}

William Optics ZenithStar 66 apo: 66mm f/5.9 SD apochromat, rotating dual-speed Crayford focuser, choice of two colors, hard case ..... **398**^{00}

William Optics ZenithStar 66 triplet apo: 66mm f/7 ED triplet apochromat, rotating dual-speed Crayford focuser, soft case ..... **548**^{00}

William Optics ZenithStar 80 ED: 80mm f/6.8 doublet apochromat, rotating dual-speed Crayford focuser, 1.25" dielectric diagonal, soft case ..... **598**^{00}

William Optics Megrez Fluorite: 80mm f/6.9 "fluorite" doublet apochromat, rotating dual-speed Crayford focuser, hard case ..... **848**^{00}

TeleVue Dioptrx eliminates eyeglasses when observing.

$98

TeleVue Dioptrx astigmatism-correcting lenses attach to TeleVue eyepieces so you don't have to wear youe eyeglasses to observe.

TeleVue Dioptrx lenses come in 0.25 diopter steps from 0.25 to 2.50 diopters, plus 3.00 and 3.50 diopters.

Each is made of precision-ground multicoated optical glass. They work with the following TeleVue eyepieces only: 26 and 31mm Type 5 Naglers; 22, 27, 35, and 41mm Panoptics; 22, 40, and 55mm Plössls; all Type 4 Naglers; and all Radians.

Get a $158^{95} value accessory kit for $49 when you buy a Celestron telescope.

This **Celestron Telescope Accessory Kit** normally sells for $99 and is worth every penny. But now, through the end of the year, you get this nine-piece kit for only $49 when you buy any Celestron telescope priced at $199 and up!

The kit is full of useful accessories. You get 12.5mm and 32mm 1.25" Plössl eyepieces, a 1.25" 2x Barlow to double the power of all your eyepieces, four 1.25" filters for lunar and planetary observing (orange, blue, green, and neutral density), a no-battery flashlight that generates and stores power just by shaking it, all in a fitted aluminum-finish case – *and all for only $49!*

12 volt power to the people for only $59^{95}!

You can recharge a **Celestron Power Tank** battery many times, saving you the cost of buying flashlight batteries every few weeks to power your scope. 7 amp hour Power Tanks start at only **$59.95**.

astronomics. No hard sell. No guesswork. Just honest advice, the time to make sure you get the right telescope and accessories, and a good price. Call us toll free at (800) 422-7876 and find out for yourself.

Reader's Digest calls the Celestron SkyScout one of the "Best of America."

$399 freight paid

The May issue of *Reader's Digest Magazine* named the 100 best things in America, and the **Celestron SkyScout** was named the "Best Star Finder." This award-winning handheld non-magnifying GPS-based personal planetarium identifies or locates more than 6,000 celestial objects visible to the unaided eye, then tells you their facts and history. You can use the SkyScout to learn the legends, myths, and sights of the sky.

There's a scrolling 5-line text and graphics display. Supplied earbuds let you hear the text so you don't have to look away from the sky to read it. Optional speakers let others hear, too.

The SkyScout transforms the night sky into a planetarium for stargazers, families, and students. It makes identifying what's in the sky easier than ever before.

All no-guesswork Celestron *GPS* SCTs are in stock.

Celestron 8" f/10 CPC800 **$1899**

It's easy to find your way around the sky with a **Celestron CPC**. Just point it at any three bright lights in the sky (3 stars, or 2 stars and a planet or the Moon), and the CPC will find over 45,000 deep space objects for you at the touch of a button.

You don't have to enter your time or location or memorize a star chart to use a CPC. Its built-in GPS system and a few anonymous lights in the sky are all you need.

Celestron's CPC Schmidt-Cassegrains come with all the features you need to start go-to observing immediately.

8" **CPC800**, Starbright multicoatings ... **$1899**^{00}
8" **CPC800X**, XLT multicoatings ..... **1999**^{00}
9¼" **CPC925**, Starbright multicoatings .. **2349**^{00}
9¼" **CPC925X**, XLT multicoatings ..... **2499**^{00}
11" **CPC1100**, Starbright multicoatings . **2599**^{00}
11" **CPC1100X**, XLT multicoatings ..... **2799**^{00}

Get a $399 Deep Sky Imager Pro CCD camera for $129 when you buy a Meade telescope.

The **Meade Deep Sky Imager Pro** CCD camera sells for $399. But, through August 31, you can get the DSI Pro for only $129 when you buy a Meade LXD75, LX90, LX200, or RCX400 telescope!

The monochrome DSI Pro is loaded with features like NASA-developed "Drizzle" software that sharpens the resolution and quadruples the size of your LX90, LX200, or RCX400 deep space photos. And the filter set for tri-color imaging, normally $199, is only $99 if bought with camera and scope.

The DSI Pro opens up a whole new way to observe with a Meade telescope. Best of all, you save a total of $370 on the DSI Pro and color filter set when you buy them along with your LXD75, LX90, LX200, or RCX400.

A Telegizmos protects your scope day and night.

A **Telegizmos** scope cover protects your telescope from sun and dew. NASA-developed to insulate spacecraft, these aluminized covers are strong, light, and more durable than Mylar. Prices start at only $29.

Outer space is infinite. Your car's back seat is not.

Meade 10" f/5 standard LightBridge **$649**

Meade LightBridge Dobsonians use a truss-tube design that lets even the big 12" models break down into a few small packages that easily fit into a compact car. One person can transport even the largest Meade LightBridge to a dark sky site and set it up on their own.

All Meade LightBridge Dobs have a 2" machined aluminum Crayford-style focuser with a 1.25" eyepiece adapter. The battery-operated fan on the metal primary mirror cell assures fast cooling of the diffraction-limited BK7 optical glass mirror. No tools are needed to assemble and break down each scope in the field.

Standard models have a 1.25" 26mm Super Plössl eyepiece, a red dot finder, and Teflon bearings. Deluxe models have a 2" 26mm 70° field QX eyepiece, an illuminated finder with four different reticle patterns, and roller bearings for smooth hitch-free motion at the touch of a finger.

The prices below include the shipping from the Meade factory.

8" f/6 standard LightBridge ..... **$469**^{00}
8" f/6 deluxe LightBridge ..... **569**^{00}
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ASK ASTRO

Astronomy's editors and experts from around the globe answer your questions about the cosmos. This month: cosmological distances, antique scope magnifications, and can dark matter be photons?

CONFUSING UNIVERSE

Q: If nothing can travel faster than light, and the universe is 13.7 billion years old, how can two galaxies lie 10 billion light-years from us in opposite directions? — BILL LAWRENCE, PORT HADLOCK, WASHINGTON

A: Distances to objects in the universe refer to their values today, not the time when their light was emitted. Remember, the universe is expanding (the fabric of space is stretching), therefore, light traveling through space will also be stretched.

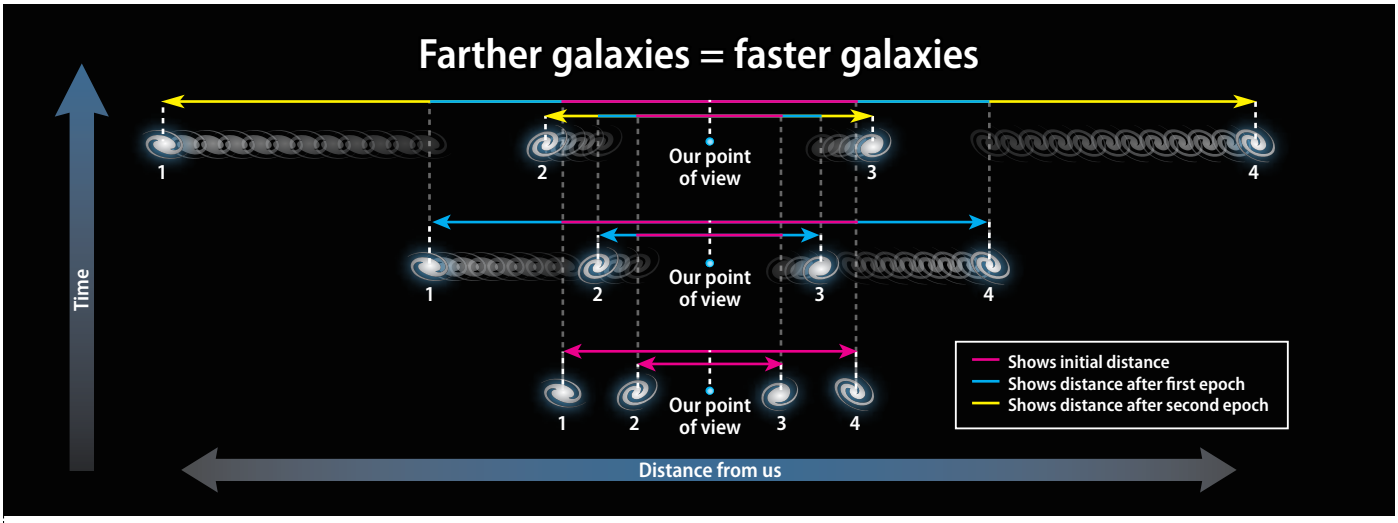
If an object is 10 billion light-years away, this doesn't imply that it took the light 10 billion years to travel this distance — the universe is expanding and was smaller in the past. So, light that crossed 1 mile in the early universe stretches with time, and, at some later time, becomes 2 miles, and, still later, 3 miles, etc. Therefore, the total distance in light-years as measured today is greater than the actual time of travel (as measured by a stopwatch) multiplied by the speed of light. The most distant object we can see in the universe today — that is, the limit of the observable universe — would be roughly 45 billion light-years away, even though the universe itself is only about 13.7 billion years old.

The idea that nothing can move faster than light is potentially misleading. Relative velocity does not make sense unless the specific objects are close to each other. It is in this limit where the laws of Einstein's theory of special relativity, and this statement, apply. The expansion of the universe, on the other hand, is actually the stretching of space and is not limited by special relativity. Any given distant galaxy may look like it is receding from us at great speed — even apparently faster than the speed of light — but this is only because the "fabric" of space between the object and us is stretching.

Finally, if we see two galaxies in opposite directions, and each is 10 billion light-years away, this does not necessarily mean they are 20 billion light-years away from each other. The reason is complicated: In cosmology, there are several definitions of distance depending on which measuring technique we use.

For example, we can infer distance to an object from the amount of light we collect using a camera attached to a telescope. We call this the luminosity distance. Or, we can measure the distance based on the angular size of the object as seen through the telescope. This is called the angular-diameter distance. In neither of these definitions is the total distance between two objects equal to twice the distance to each one.

Not surprisingly, the various definitions agree on scales where separations are smaller than 100 million light-years. This is far outside of our galaxy, but, nevertheless, much closer than many other objects we see with today's powerful telescopes. Beyond this short-distance limit, distances to two objects located opposite each other relative to us can't be added to get their



ASTRONOMY: ROEN KELLY

THE UNIVERSE'S EXPANSION causes most galaxies to recede from each other, apparently moving faster than the speed of light. Light's "speed limit" applies only to short distances, which are governed by special relativity. But space itself is expanding, and, therefore, galaxies farther from us have increasingly higher velocities, which can be faster than the speed of light.

mutual separation. — **DRAGAN HUTERER,** KAVLI INSTITUTE FOR COSMOLOGICAL PHYSICS, UNIVERSITY OF CHICAGO

CLASSIC OBSERVING

Q: What typical magnifications did 19th-century observational astronomers use for lunar and planetary viewing?

— **CLYDE BOYER,** SPRING CREEK, NEVADA

A: Observers often used the large refractors built in the 19th century for planetary observations. Through large telescopes like the Lick 36-inch refractor, the 26-inch U.S. Naval Observatory (USNO) refractor, and the 40-inch Yerkes Observatory refractor, **magnifications of 400x to 600x were not uncommon.** On nights when the seeing could be described only as "legendary," magnifications of 750x, 1,000x, and higher occasionally were employed.

General planetary observations don't require ultrahigh magnifications. Astronomers used them only when they were observing tiny objects.

Seldom, however, are these giant refractors pointed at the Moon. It's just too bright.

Big telescopes have several advantages over their smaller counterparts. First, the bigger the scope, the more light it collects, which makes images brighter. Second, a telescope's resolution — how clearly it shows the image — depends on two factors: aperture (the size of the telescope's lens or mirror) and seeing (atmospheric steadiness). So, even if the magnification used by some 19th-century professionals equals what a modern-day amateur astronomer might employ, the view through the larger scope would show finer details.

NINETEENTH-CENTURY refractors employed high magnifications. Astronomers observing with the 40-inch at Yerkes Observatory in Williams Bay, Wisconsin, typically used magnifications higher than 400x. ERNIE MASTROIANNI

As an example, American astronomer Edward Emerson Barnard (1857–1923) discovered Amalthea, the fifth satellite of Jupiter, on September 9, 1892, using an eyepiece that yielded 520x on the 36-inch Lick Observatory refractor. I have viewed many objects through 8- to 12-inch telescopes at this magnification or higher, but through none of those scopes would I have any chance of observing Amalthea.

Barnard used 1,500x in 1895 to study whether Jupiter's large moons were oblong. For his research of the asteroids Ceres, Pallas, and Vesta, and Saturn's moon Titan, he wouldn't even observe unless the atmosphere would bear 1,000x — enough magnification to show a disk. A few times, he actually observed these objects at 2,600x. Likewise, Barnard observed asteroid Juno at 1,430x and 1,700x to make disk measurements between 0.2" and 0.26".

At the USNO in Washington, American astronomer Asaph Hall (1829–1907) studied Saturn through the 26-inch Clark refractor. Hall used four eyepieces that provided magnifications of 390x, 400x, 600x, and 800x, although he used the last one rarely because of the bad seeing over Washington.

In Flagstaff, Arizona, American astronomers Percival Lowell (1855–1916) and William Pickering (1858–1938) preferred magnifications of 440x and 617x while sketching Mars during its 1894 opposition. They used higher powers for tiny measurements (such as the size of the polar cap). They made these observations through an 18-inch telescope. When the 24-inch refractor went into use, Lowell used similar magnifications for later martian observations. — **MICHAEL E. BAKICH,** SENIOR EDITOR

MISSING MASS, MAYBE?

Q: Is there any way photons could contribute to the mysterious dark matter? — JAMES BUTLER, LIBERTYVILLE, ILLINOIS

A: Because photons mediate all electromagnetic interactions, limits on the mass of the photon are extremely stringent. Even a tiny mass would produce easily measurable effects. Some of the best mass limits come from studies of Earth's magnetic field, but there are many other independent measurements that are nearly as good. All of them indicate the photon's mass must be less than about 10^{-50} kilograms. Compared to the limit on the neutrino mass, which is about an electron volt, or 10^{-36} kg, the photon's mass is at least 14 orders of magnitude smaller.

The photon density left over from the Big Bang — the cosmic microwave background radiation — is comparable to the neutrino density (a few hundred per cubic centimeter). The contribution of neutrinos to the universe's mass is at most about 1 percent. Because the photon is at least 10^{14} times lighter than the neutrino, **photons cannot contribute significantly to the universe's mass.** — **DAVID CASPER,** UNIVERSITY OF CALIFORNIA, IRVINE

Send your questions to: askastro@astronomy.com; or write to: Ask Astro, P. O. Box 1612, Waukesha, WI 53187. Be sure to tell us your full name and where you live. Unfortunately, we cannot answer all questions submitted.

IN THE KNOW

OBSERVABLE UNIVERSE:
The region of the universe that astronomers can observe. It's governed by the finite speed of light and the universe's age — 13.7 billion years. As far as we know, beyond this limit, the universe could be infinite. Many use the term *universe* to mean the observable universe.

ELECTRON VOLT:
The amount of energy an electron gains when it's accelerated through an electric field produced by 1 volt; abbreviated eV.

Massive stars die in fantastic style. Their remains form spectacular telescopic sights. /// BY STEVE GOTTLIEB

How to observe exploded stars

A violent event called a supernova

happens in a galaxy once or twice a century. A star heavier than about 12 solar masses ends its brief life span in a dramatic explosion called a core-collapse supernova. The supernova ejects most of the star's material while creating heavy elements such as lead, silver, and gold. This process forged many of the elements in our bodies and the solar system.

The blast releases as much energy as all of the other stars in the galaxy combined. The star then shines intensely enough to be visible in the daytime for several days.

The blast's expanding shock wave propagates into space, compressing and heating interstellar molecular clouds. The star's debris mixes with the interstellar medium, forming a delicate supernova remnant (SNR). It's a spectacular telescopic target. Radio and X-ray surveys have revealed 265 such SNRs — a type of nebula, or glowing gas — but only a few of them are visible in backyard scopes. Follow along for a tour of the most spectacular sights.

THE CRAB NEBULA (M1) harbors a pulsar at its center. Shocked gas and interstellar material give this supernova remnant its twisting filaments. BRIAN LULA

A cosmic motivation

On July 4, 1054, Chinese astrologers announced the appearance of a "guest star" in Taurus. This supernova quickly surpassed Venus in brightness and remained visible for 23 days during daylight and 21 months at night. The debris from this event is an SNR now known as the **Crab Nebula** (M1).

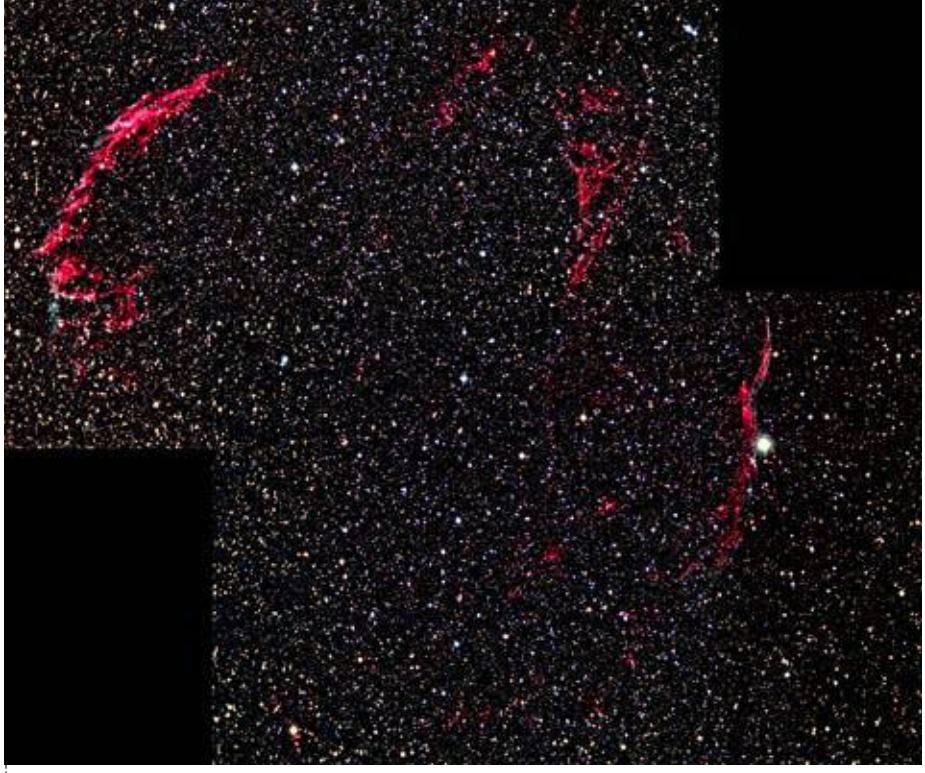
In 1731, British physician and amateur astronomer John Bevis made the first telescopic observation of the 1054 remnant. French comet-hunter Charles Messier rediscovered the nebula in 1758, describing "a whitish light, elongated in the shape of a flame of a candle, discovered while observing the comet of 1758." This observation inspired Messier to compile his famed catalog of 103 deep-sky objects; he placed this SNR first, designating it M1.

When Irish astronomer William Parsons (the third Earl of Rosse) trained his 36-inch reflector on M1 in 1844, he described "resolvable filaments singularly disposed, springing principally from its southern extremity, and not, as is usual in clusters, irregularly in all directions." A remarkable sketch by Lord Rosse, published in the *Philosophical Transactions of the Royal Society of 1844*, shows filaments or appendages streaming out the sides and inspired the name "Crab Nebula."

In 1967, Cambridge University graduate student Jocelyn Bell and advisor Anthony Hewish used a radio telescope to discover the first pulsar — a rapidly rotating neutron star with an intense magnetic field producing a narrow beam of radiation that sweeps through our line of sight. Before this observation, astronomers suspected neutron stars were the corpses of massive stars that died in supernova explosions. One year later, in 1968, astronomers discovered the Crab Nebula's corpse star: a 16th-magnitude pulsar that rotates about 30 times a second. A

Steve Gottlieb *gave readers a tour of Wolf-Rayet bubbles in the February 2006 issue. He observes under the skies of northern California.*

THE JELLYFISH NEBULA (IC 443) in Gemini exhibits tendrils of nebulosity hanging from the central object. This wreckage is from a star that exploded roughly 5,000 years ago. MARK HANSON



THE VEIL NEBULA in Cygnus shows off a bubble structure that makes its origin — an explosion — apparent. You can split the Veil into three objects from east to west: the Waterfall, Pickering's Wedge, and the Witch's Broom. ADAM BLOCK

gradual slowdown of the pulsar provides the energy for the glowing nebula.

The Crab Nebula is a snap to locate — roughly 1° northwest of 3rd-magnitude Zeta (ζ) Tauri — but the nebula will appear featureless in light-polluted skies. For the best view of any SNR, head to a dark site, and use a narrowband filter to increase contrast.

At magnitude 8.5, the Crab is faintly visible in a 50mm finder scope or large, handheld binoculars. A 6-inch scope will reveal a 6' by 4' glow with pinched-in sides. This pinch creates an irregular potato shape with extensions toward the northwest and southeast. In my 18-inch, I see subtle mottling in the interior, while the nebula's periphery looks tattered. An OIII filter brings out some filamentary streaks, particularly on the southwest side.

The magnificent

The premier visual SNR is the **Veil Nebula**. Its three main sections (NGC 6960 and NGC 6992/5) form a partial cosmic wreath nearly 3° in diameter. Astronomers previously estimated the Veil was at least 2,500 light-years away, but research using the Hubble Space Telescope (HST) and the Far-Ultraviolet Spectroscopic Explorer (FUSE) gives a shorter distance of 1,500 light-years. These data have dropped the nebula's estimated age from 30,000 years to less than 10,000.

William Herschel discovered the Veil more than 220 years ago, and, until 1980, it was considered a challenging target. The situation changed with the introduction of nebula filters. Today, the Veil is a star-party favorite. You can easily locate it by pointing your scope at 4.3-magnitude 52 Cygni.

After observing the Veil from a dark site countless times over the past 25 years, I'm still astonished by its intricate, lacy threads.

With my 10x30 image-stabilized binoculars, the eastern section, NGC 6992/5, is faintly visible as a narrow, ghostly arc in a rich star field. An 80mm refractor at low power will frame both the eastern and western arcs and reveal the Veil as a huge, glowing bubble.

With an 8-inch scope and a narrowband filter, the main arcs resolve into delicate, filamentary wisps. The western arc, NGC 6960 or the "Witch's Broom," is more than 1° long and pierced by 52 Cygni. The southern end broadens and bifurcates, while the brighter northern end tapers to a spike.

Larger scopes show a breathtaking view, in which the brighter filaments take on a noticeable electric appearance. The more detailed eastern arc, sometimes dubbed "The Waterfall," has a surreal amount of lacy, filamentary detail and multiple strands that appear three-dimensional and braided. Feathery, side-branching nebulosity streams to the west on the nebula's southern end.

A triangular piece known as "Pickering's Wedge" sits between the two main branches on the northern side. This 45'-long triangular wisp is widest at the northern end and shows a split. It displays much of the same wispy structure as its brighter counterparts.

The sky creature

As the nickname suggests, the **Jellyfish Nebula** (IC 443) is a strange creature. This expanding bubble of debris has sculpted a shell of shocked gas about 50' northeast of 3rd-magnitude Eta (η) Geminorum. Tendrils of nebulosity appear to dangle from the SNR's circular rim and create the jellyfish appearance.

The SNR is slamming into a nearby dense molecular cloud, crushing and shocking the cloud's molecular hydrogen (H_2) and possibly initiating star formation in the region. Astronomers estimate IC 443 is roughly 5,000 years old.

IC 443 is generally considered a telescopic challenge object — both William and John Herschel missed it during their comprehensive sky surveys. Edward Emerson Barnard and Max Wolf photographically discovered the Jellyfish in the 1890s. Observers can glimpse IC 443 in an 8- or 10-inch scope using a narrowband OIII filter. Through larger backyard scopes, the SNR shows a fair amount of detail.

OBSERVE THESE SUPERNOVA REMNANTS

Name	Constellation	Right ascension (2000.0)	Declination (2000.0)	Size
Crab Nebula (M1)	Taurus	5h35m	22°01'	6' by 4'
Veil Nebula (NGC 6960, NGC 6992/5)	Cygnus	20h51m	30°40'	230' by 160'
Jellyfish Nebula (IC 443)	Gemini	6h18m	22°49'	50' by 50'
Pencil Nebula (NGC 2736)	Vela	9h00m	45°57'	10' by 20'
Sharpless 2–91	Cygnus	19h36m	29°59'	1' by 14'

THE PENCIL NEBULA (NGC 2736) is the Vela Supernova Remnant's brightest strand. Shock-compressed interstellar gas results in twisted filaments of nebulosity. This SNR is one of the nearest to Earth (just 815 light-years away). DANIEL VERSCHATSE

In my 18-inch at 64x, the brightest section appears as a gently curving band of nebulosity oriented northwest to southeast and roughly 10' by 3'. A well-defined arc forms the eastern boundary southwest of the bright arc. At the bright arc's southern end, the glow dims and appears to hook toward a triangle of stars.

A southern delight

At a distance of roughly 815 light-years, the **Vela Supernova Remnant** is one of the nearest. Its faint tendrils of nebulosity are splashed across 5° of sky.

Even though the Vela SNR is fainter than the Veil, you can trace much of the Vela in an 8-inch using an OIII filter. Larger amateur scopes will show multiple strands of wide, diffuse swaths of nebulosity and delicate, twisted gas plumes that span numerous eyepiece fields of view.

In 1968, astronomers discovered a pulsar spinning 11 times per second at the Vela's heart. By carefully timing the "slowdown" rate, astronomers determined the supernova occurred 11,000 years ago.

To explore the Vela SNR, begin just north of 4th-magnitude Epsilon (ε) Velorum, located at right ascension (R.A.) 8h37.6m and declination (Dec.) –43°00' (2000.0), and follow a meandering stream of nebulosity to the southwest. You can follow another long, narrow filament to the west of the 5th-magnitude double star HD 72127 at R.A. 8h29.5m and Dec. –44°43'.

The Vela SNR's brightest strand is the **Pencil Nebula** (NGC 2736). This isolated linear filament is 4.5° east of the Vela pulsar. The nebula's form suggests the supernova's shock front has compressed a dense region of interstellar gas in the galactic plane. When I observed the Pencil Nebula from Costa Rica with a 13.1-inch scope and a UHC filter, I found it easily. It's a 20'-long splinter of light extending southwest to northeast with weak filamentary structure and hints of two intertwined threads.

Cygnus' little-known SNR

In 1977, astronomers Theodore Gull, Robert Kirshner, and Robert Parker were conducting an emission-line survey of the galactic plane when they unexpectedly found a huge filamentary shell in Cygnus. This shell (G65.3+5.7) is a whopping 4° by 3.3°. Subsequent radio and X-ray observations confirmed this incomplete ring is a SNR.

The shell's brightest section is **Sharpless 2–91**, a strip of nebulosity that resides less than 3° northeast of Albireo (Beta [β] Cygni), a double star with magnitudes 3.3 and 5.5. Due to Sh 2–91's low surface brightness, this ethereal thread is a challenge to detect among the maze of Milky Way stars. Fortunately, like other SNRs, it exhibits strong OIII emission. A narrowband filter increases contrast and enhances the view.

When I first took a look with my 18-inch in 2001, I was amazed to find a gossamer filament, just 1' wide but stretching across 14' of a crowded Milky Way field. This ghostly wisp dangles from an 8th-magnitude star on its southwest end. From there, the nebula gracefully arcs to the northeast, passing by a 9.5-magnitude star. With careful viewing, portions of the filament resolve into two strands. To find this obscure SNR, head to a dark site, and search 15' south of 4.7-magnitude Phi (φ) Cygni.

Scientists using data from the European Space Agency's International Gamma-Ray Astrophysics Laboratory (INTEGRAL) recently determined a supernova rate of 2 per century in our galaxy. Although Tycho Brahe and Johannes Kepler witnessed supernovae in 1572 and 1604, respectively, a galactic supernova has not been observed in the past 400 years — one is long overdue.

While waiting for the next one, why not grab your telescope, head to a dark site, and spend some time exploring these objects. You'll be witnessing the aftermaths of one of nature's grandest spectacles.

Yankee Robotics' new CCD camera combines maximum sensitivity, low noise, and a great price. /// BY BOB FERA

Yankee digital dandy

The field of advanced charge-coupled device (CCD) imaging is dominated by high-quality instruments from a few well-known manufacturers, such as Santa Barbara Instruments Group (SBIG), Finger Lakes Instrumentation (FLI), and Starlight Express. Recently, a new player entered the game with a unique approach to CCD-camera design. That company, Yankee Robotics of San Diego, has introduced its Trifid-2 line of cameras and is aiming directly at the big boys.

I tested Yankee's top-of-the-line model, which features Kodak's KAF-6303E CCD detector, to see if it measures up to the competition. It does.

The first thing prospective customers will notice about the Trifid-2 is the price, which, at $6,895 (with the Class 2 imaging chip), is thousands of dollars less than competitors' cameras equipped with the same 6-megapixel KAF-6303E detector. What you get for the money is a small, light camera body with a large detector that measures 18mm by 27mm, a USB-2.0 interface, and a lifetime warranty.

Unlike some systems, the Trifid-2 does not come with either a filter wheel or an onboard guiding chip. Using the camera thus requires purchasing and integrating a third-party filter wheel from a company such as FLI or Optec, Inc. Also, you'll need an off-axis guider or a guide scope with a dedicated autoguider, such as SBIG's ST-4, ST-V, or ST-402ME. But, even after adding in these extras, the system's total cost remains less than the competition's.

THE TRIFID-2 CCD camera houses a 6-megapixel Kodak KAF-6303E CCD chip. The camera's shutter allows 1/50-second exposures. *ASTRONOMY:* WILLIAM ZUBACK

SPIRAL GALAXY NGC 6946 in Cepheus glows at magnitude 8.9 and measures 11' by 10'. This image is an LRGB composite of 180, 60, 60, and 60 minutes, respectively, through the Trifid-2 CCD camera. BOB FERA

Intelligent design

Engineers maximized this camera's sensitivity while reducing its overall electronic noise output. Yankee utilizes CCD chips without cover slips to increase light throughput and to reduce internal reflections and scattering. The chip sits in a thermally isolated pocket filled with argon. This lowers the dew point and prevents frost from forming when the chip is cooled more than 100° Fahrenheit (40° Celsius) below ambient temperature.

To combat noise, the company separated analog and digital functions onto separate circuit boards. It also installed a 200,000-gate Field-Programmable Gate Array to enable precise control of readout timing, incorporated a frame buffer so USB traffic doesn't affect image quality, and utilized high-quality components, such as gold-plated connectors, throughout the camera.

A unique design feature built into the camera is its Single Photon Performance technology, or SPP. The goal of SPP is to maximize detail and contrast in the faintest part of an astronomical image. To understand how SPP works requires a basic knowledge of how CCD chips work.

Each pixel in a CCD array records incoming light by storing electrons in the pixel's "well." Different detectors have different well capacities — the number of

Bob Fera *is a California amateur astronomer and long-time astrophotographer.*

THE TRIFID NEBULA (M20) in Sagittarius combines both emission (red) and reflection (blue) nebulosities. The author took all his images through a 12.5-inch Parallax Instruments Ritchey-Chrétien telescope at f/9, and he used Astrodon filters. BOB FERA

THIS PUMP circulates water from an ice-chest reservoir through the Trifid-2 camera to remove heat generated by the chip. High chip temperatures result in lots of electronic noise (bright dots on the images). *ASTRONOMY*: WILLIAM ZUBACK

THE DUMBBELL NEBULA (M27) in Vulpecula was the first planetary nebula discovered. French comet-hunter Charles Messier found M27 July 12, 1764. This RGB composite image combines 60-minute exposures through each filter. BOB FERA

electrons each pixel can hold before they spill over, or bloom, into adjacent pixels. The Trifid-2's KAF-6303E chip has a well capacity of 100,000 electrons.

Like other high-end CCD cameras, the Trifid-2 uses a 16-bit analog-to-digital converter, which allows 65,536 discrete brightness values (analog-to-digital units, or ADU) for each pixel. So, the 100,000 electrons must be mapped into a numeric range between 0 and 65,535 before the image is downloaded to the computer. Most manufacturers do this by mapping multiple electron-counts into a single ADU value.

For example, electron-counts of one and two might both be assigned an ADU value of one; electron-counts of three and four may become an ADU count of two, etc.

THE IRIS NEBULA (NGC 7023) in Cepheus scatters and reflects nearby starlight. This process gives the nebula its distinctive blue color. This LRGB image combines exposures of 120, 60, 60, and 60 minutes, respectively. BOB FERA

This process is not only inaccurate, it reduces image contrast.

Yankee Robotics chose to map electron-counts to ADUs in a one-to-one fashion from 0 up to 65,535. Electron-counts between 65,535 and 100,000 all map to an ADU value of 65,535. In other words, one electron equals one ADU, two electrons equals two ADU, etc. Most of the detail astrophotographers seek lies in the low ADU (i.e., faint) regions of an image. This technique emphasizes that low-ADU information at the expense of detail in the brightest highlights, of which stars are the usual contributors.

Testing and judgment

The prototype camera I tested contained an engineering-grade chip, which is good, but it ranks a bit lower in quality than those in the final-version Trifid-2 cameras. Still, I found it to be exceptionally sensitive and noise-free. I imaged several bright and dim summer objects. I used Astrodon LRGB and Hydrogen-alpha (Hα) filters with my 12.5-inch f/9 Parallax Instruments Ritchey-Chrétien reflector.

Amazingly, only one image during this entire review required the application of any kind of noise-reduction techniques during processing. I found this surprising because, for most of the photos, I took fewer individual subexposures through each filter than I normally do. (As most astroimagers know, more individual exposures translate to a higher signal-to-noise ratio in the final result.)

The Hα component of my Crescent Nebula (NGC 6888) image comprised only two 30-minute exposures. I couldn't believe how little background noise appeared when I "stretched" the image (with *Photoshop*) to reveal its faint details.

The Trifid-2 takes a bit longer to get up and running than other CCD cameras. For example, the camera is not yet supported "out of the box" by popular camera-control software packages most astroimagers use. But Yankee Robotics includes driver plug-ins for *MaxIm/DL* (which I used for this test), *CCDSoft*, and *AstroArt*. So, adding hardware support is as simple as dragging and dropping a few files on your computer once you've installed the main Yankee Robotics software. The instructions for doing this are straightforward and worked without any hitches.

On the hardware side, the camera requires chilled water to cool the CCD chip to operating temperature. Along with the Trifid-2, Yankee Robotics supplies a submersible 12-volt pump with all of the hoses and fittings you need, as well as a small ice chest and freezer pack. Setting it up was a trivial matter, and the system easily kept the chip cooled to –4° F (–20° C), even with ambient temperatures well over 68° F (20° C). One tiny critique here: The ice chest, while a nice touch, is a bit small for the job. I found the ice pack melted after a few hours, and the water became warm by the end of a night of imaging. The water kept the chip sufficiently cool, but I felt more comfortable after I switched to a larger ice chest with more water and a larger freezer pack. If your system is in one location, and you image from a remote site, consider replacing the ice chest with a small electric water-chilling system.

File downloads to the laptop were slower than I expected, given the high-speed USB-2.0 interface. The bulk of the download time results from transferring the image from the chip to the camera's frame buffer. Because the camera is optimized for high sensitivity and low noise, Yankee Robotics' engineers found that reading the data from the chip too fast introduced unwanted electronic artifacts into the image. This is an area of ongoing

NGC 6992/5 form part of the Veil Nebula's eastern segment in Cygnus. The gas we see rushes outward from a star that exploded as a supernova between 5,000 and 10,000 years ago. The author created this LHαRGB image by combining exposures of 100, 90, 50, 50, and 50 minutes, respectively. BOB FERA

/// SNAPSHOT

YANKEE ROBOTICS TRIFID-2 CCD CAMERA

Diameter: 4.5" (114mm)
Depth: 2.75" (70mm)
CCD chip: Kodak KAF-6303E
Chip size: 1.0" by 0.71" (27mm by 18mm)
Total pixels on chip: 6,291,456 (6 megapixels)
Includes: Cooling system, control software
Price: $6,895 (with Class 2 imaging chip)

Contact information:
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THE CRESCENT NEBULA (NGC 6888) in Cygnus shines because energy from a hot Wolf-Rayet star causes the gas to glow. The star's radiation pressure also created this object's curved shape. The author created this LHαRGB image with exposures of 60, 60, 50, 50, and 50 minutes, respectively. BOB FERA

development, and the engineers are confident in their ability to increase the chip-readout speed without compromising image quality. Even with all of that, image downloads took only 17 seconds, which is quite respectable for a 12-megabyte file.

During the test period, I found Yankee Robotics' support to be outstanding. I performed my tests using "beta" versions of the camera software, as the company continually worked to improve the camera's already remarkable performance.

Overall, the Trifid-2 impressed me. The quality of its images combined with a manufacturer dedicated to ultimate performance makes for a winning pair. Add to this a relatively low price, and this camera's a winner. A

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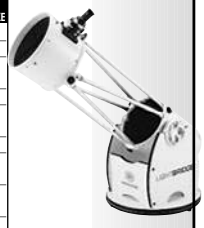

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On September 22, shadow-chasers will trek south to view an annular eclipse of the Sun. /// BY MARTIN RATCLIFFE

Glimpse the great ring of fire

Sunrise will be remarkably different

the morning of September 22 for coastal inhabitants of Guyana, Suriname, and French Guiana on the northeastern coast of South America — the only major landfall for the track of this year's only annular solar eclipse. The familiar orange-yellow ball rising above the waters of the South Atlantic Ocean will appear instead as a sharp horn marking the upper cusp of the eclipsed Sun.

Thirty minutes later, the annular eclipse will reach maximum, temporarily halting the brightening of the morning sky. A brilliant ring of fire, with the Moon neatly centered within the Sun's blazing disk, will stand 8° above the eastern horizon.

An annular eclipse occurs when the Moon passes between Earth and the Sun and the Moon appears too small to cover the Sun entirely. While changes in the Moon's apparent size are not noticeable with the eye, our satellite's distance from Earth varies by up to 31,000 miles (49,900 kilometers) during the course of its month-long elliptical orbit. The Moon's apparent size shrinks up to 4' (12 percent) as it goes from perigee, when it's closest to Earth, to apogee, its farthest point from Earth.

Should an eclipse occur when the Moon is at apogee — such as on September 22, when apogee occurs some 6 hours before the eclipse — an annular eclipse results. The name comes from the Latin word *anulus*, which means "ring."

Annular eclipses are more common than total solar eclipses. During this century, 77 annular and 72 total eclipses will occur. Another 6 "hybrid" eclipses also will take place. Hybrids are annular along most of the eclipse track, but viewers in certain locations experience a brief moment of totality.

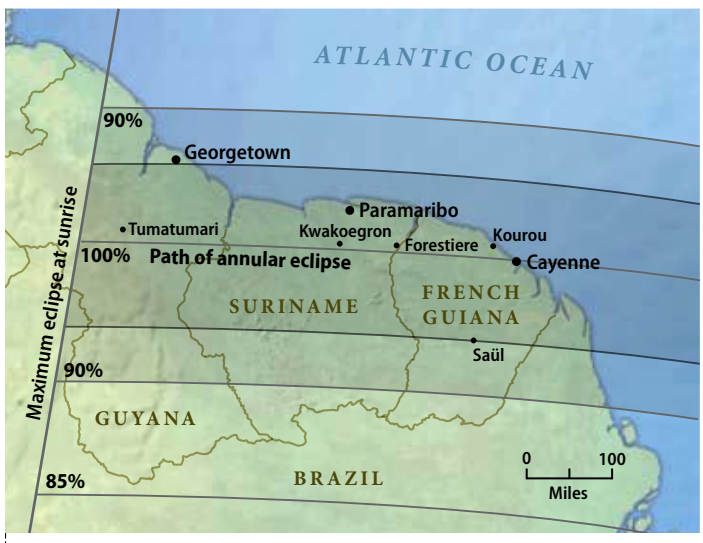
The main event

On September 22, the Moon's diameter is 29.4', while the Sun's diameter is 31.9'. The Moon covers 93.5 percent of the Sun's diameter. This eclipse occurs the day before Earth reaches its autumnal equinox, when day and night are of equal length. The Sun appears directly overhead at the equator,

Global eclipse path

SOUTH AMERICA and the mid-Atlantic are the best places on Earth to see the annular eclipse of the Sun and its partial phases September 22. *ASTRONOMY:* ROEN KELLY

Landfall occurs over South America



THE ECLIPSE TRACKS over land in the South American countries Guyana, Suriname, and French Guiana. *ASTRONOMY:* ROEN KELLY

THE ANNULAR ECLIPSE shown here tracked across Africa, Portugal, and Spain October 3, 2005. Stefan Seip of Stuttgart, Germany, took this image from Spain.

and, due to this geometry, part of this eclipse track crosses the equator.

Never look directly at the Sun without proper eye protection. During the few minutes an annular eclipse is at its peak, the fine, thin ring of sunlight is still more than 10,000 times brighter than the Full Moon.

The dark sky and spectacular corona visible during a total solar eclipse never appear during an annular eclipse. The sky remains bright blue. The landscape takes on a duller yellowish hue compared to full sunlight. Observers within the eclipse's central track will notice falling temperatures.

The eclipse will be visible from Suriname's capital city, Paramaribo, where maximum eclipse occurs at 6:51 A.M. The Sun will be at 5° altitude, and annularity lasts 5 minutes, 1 second. The city lies north of the center line, so the Moon will be displaced slightly from the Sun's center.

A good place to view the annular eclipse is from Cayenne in French Guiana. This coastal city lies 6 miles (10 km) south of the center line, close to the European Space Agency's launch site at Kourou. Observers will see Venus rise about half an hour before the Sun. Sunrise occurs about 6:18 A.M. when the cusp of the partially eclipsed Sun rises. At 6:53 A.M. and 8° altitude, annularity begins and lasts for 5 minutes, 42 seconds.

Following the early morning view from South America, the central eclipse track races across the South Atlantic, crossing the Tropic of Capricorn midway between South America and southern Africa, rounding South Africa far to its south before ending just short of the volcanic Heard Island Marine reserve, located in the sub-Atlantic waters less than 700 miles (1,127 km) off the Antarctic coast. King penguins living on Heard Island likely will be the last Earth dwellers to see this eclipse, but only in partial phases. The Sun sets on the island before annularity is reached.

Eclipse roundup

The last annular eclipse to cross the United States occurred May 10, 1994. Upcoming annular solar eclipses occur January 26, 2009 — visible in Indonesia — and January 15, 2010 — observable in Africa and southeast Asia.

North American observers are outside the path of the September 22 eclipse and will have to travel to South America to glimpse the great ring of fire or wait until May 20, 2012, when the next annular eclipse of the Sun passes over North America.

Martin Ratcliffe, *the former president of the International Planetarium Society, coauthors* Astronomy*'s "The Sky This Month."*

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IMAGINOVA

Tele Vue's new TV-60is offers easy, high-resolution astroimaging.

/// BY ROBERT REEVES

Big results from a small package

Astroimagers will appreciate Tele Vue's new TV-60is 2.4-inch (60mm) f/6 APO telescope. The scope has standard and optional features optimized for CCD and SLR imaging systems. The TV-60is' fine-focusing ability and a high-quality lens bridge the gap between piggyback

astrophotography — imaging with a camera mounted on a telescope's optical tube — with camera lenses and prime-focus telescopic photography — imaging with a lensless camera mounted where the telescope comes to focus.

This new offering from Tele Vue is based on the Tele Vue 60, a two-element, f/6 apochromatic refractor, but with a few astroimaging-friendly modifications. In place of the 2" diagonal found on the TV-60, the TV-60is features a thread-in field flattener that allows pinpoint photographic focus across a 35mm camera focal plane.

T-threads on the rear of the field flattener allow attachment of virtually any kind of photographic device.

The TV-60is sports an adjustable lens cradle and dovetail mounting bar. Other features include a retractable lens hood with an attached bracket to mount an optional Tele Vue Qwik Point finder and an included Focusmate 6:1 reduction, slow-motion focuser to achieve precise focus. An optional, but indispensable, accessory is Tele Vue's digital focusing micrometer. The micrometer measures the position of the focuser to an astonishing 0.0001".

FINE FOCUS is made easy with Tele Vue's digital focusing micrometer. This optional accessory measures the focuser's position to an astonishing 0.0001" (0.00254 mm).

AURIGA'S FLAMING STAR NEBULA (IC 405, right) and emission nebula IC 410 offer a beautiful sight. The TV-60is combined with a Canon 300D digital SLR captured this image.

At a glance

The TV-60is arrived packed in a rectangular, foam-lined canvas carrying bag featuring handles and a shoulder strap. The instrument is 11.5 inches long with the field flattener installed and fits snugly into the carrying-case foam cutout. It is well-protected for traveling. A nice touch is a removable foam insert to allow any 35mm film or digital camera to be stored attached to the TV-60is. My Canon 300D digital SLR now lives in the case attached to the TV-60is.

With a 4°-per-inch field of view at the focal plane, the TV-60is can display a large sky area. The scope also resolves many deep-sky objects. Tele Vue's astrophotography lens is an absolute cluster-buster under urban skies and a real deep-sky beauty under dark skies. Unlike most conventional camera lenses, the TV-60is retains sharp focus on an object anywhere in its field of view. Stars are round all the way to the edge of the field, without a hint of coma or

Robert Reeves *is an astrophotographer and author who lives in San Antonio. His latest book,* Introduction to Digital Astrophotography, *is published by Willman-Bell (2005).*

THE HORSEHEAD NEBULA'S (B33) distinct shape is seen above a backdrop of gas, dust, and stars. UNLESS OTHERWISE NOTED, ALL PHOTOS: ROBERT REEVES

TELE VUE'S TV-60is imaging system is shown here with TeleVue's standard dovetail plate and optional digital focusing micrometer.
ASTRONOMY: WILLIAM ZUBACK

aberration. (Coma causes stars to appear flared instead of round, while aberration typically blurs the image.)

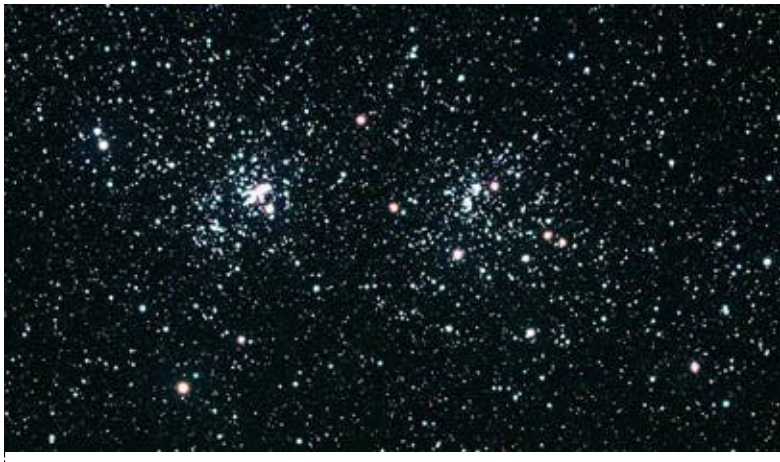
Tele Vue machines the dual-ring mounting cradle from one piece of aluminum for strength. The cradle has the same handsome, black-anodized finish used on the lens assembly. The rings are spaced 1¾" apart. The cradle is stable, and the ¼" plastic adjusting screws secure the lens barrel without marring it. The upper-front screw indexes into a detent in the lens barrel to prevent the TV-60is from slipping in the rings. The Qwik Point finder bracket on the lens hood also acts as a safety stop to prevent the assembly from accidentally falling through the rings if the screws are too loose.

The TV-60is comes with Tele Vue's Focusmate 6:1 fine-focus accessory mounted on the right side of the optical-tube assembly. This conveniently places it next to the optional digital-focusing micrometer. Wisely, Tele Vue engineered the dual-focus locking setscrews so they don't push into the moving focuser. Instead, the setscrews press onto brass clamp rings, which, in turn, securely lock the focuser.

The dovetail mounting bar has a dual ¼" by 20 thread pattern that also fits Bogen video mounts, complete with video-alignment pinholes. The spacings from the forward bolthole are ½", 1 1/16", 1 9/16", 2⅝", 3⅛", 4 3/16", and 4¾", allowing the adapter bar to be mounted on a wide variety of carriers. Threaded knobs on the dovetail bar act as additional safety stops,

THE ORION NEBULA (M42) is a deep-sky delight viewed through the TV-60is. M42 is the sky's brightest emission nebula.

THE ANDROMEDA GALAXY (M31), our nearest large companion galaxy, reveals its spiral structure in this image captured with the TV-60is. The image contains 15 exposures of 6 minutes at ISO 400.



STARS WITHIN NGC 869 (left) and NGC 884, Perseus' famed double open star cluster, are well-resolved in this 3,072x2,048 pixel image.

preventing the TV-60is mounting cradle from accidentally sliding off the bar.

Focusing power

Imaging resolution of the TV-60is is 240 line pairs per millimeter. Any lens that resolves 80 line pairs per millimeter is considered extraordinary. To make the most of the telescope's resolving power, it is crucial to adjust its fine-focus tolerance accurately.

The optional digital-focusing micrometer is, in my opinion, necessary for those who want to achieve maximum focusing accuracy. The digital-focusing micrometer is an indispensable accessory for achieving not only the finest focus, but also the easiest operation of the TV-60is. The micrometer's scale is selectable between inches and millimeters, and the scale can be re-zeroed at any point along the device's travel.

Digital single-lens reflex (SLR) users have several ways to employ the micrometer to absolutely "nail" the focus. First, visually focus through the viewfinder. Then, back up the focus .005 inch using the micrometer scale. Next, take 11 short exposures — 4 seconds at ISO 400 works well — while using the micrometer to advance the focus by .001 inch per exposure until you are .005 inch beyond the original focus. Visually examine the star images on a computer or analyze the stars' focus using software that determines each star's so-called Full-Width Half-Maximum — a star's apparent width at half of its peak brightness in an image.

Software selection of the finest star image is best; however, if no such program is available, visually examine the test exposures and look for the exposure with the faintest stars. An image out of focus by only .001 inch will have noticeably fewer faint stars. By logging the micrometer readings for each test exposure, it is possible to return to the point of best focus. With practice and good software, you can accurately set the focus to within a fraction of a thousandth of an inch.

Film astrophotographers focusing the TV-60is through the camera viewfinder often fail to realize the lens' full potential. For best film results, use an auxiliary knife-edge focuser.

Imaging with the TV-60is

Initial short-exposure tests with the TV-60is and a modified Canon 300D camera (with the infrared filter removed) from my urban back yard produced images with stunning resolution. For deep-sky work, I mounted the TV-60is parallel to an 80mm guiding refractor on an equatorial mount and guided the system with an Atik IIhs modified webcam using Steve Barkes' freeware *GuideDog*.

The TV-60is requires 55mm of back focus — the distance between the rear flange of the field flattener and the camera's focal plane — to focus the image properly. The back focus of 35mm and digital SLR cameras closely matches the TV-60is, but other imaging devices require adapters to reach the necessary back focus.

Just the facts

The weight-carrying capacity of the TV-60is is not specified; however, it has been my experience that the focuser and lens-mounting cradle can support a device equal to the TV-60is' own 7-pound weight. This

includes Santa Barbara Instrument Group's hefty ST-10 and ST-11000 CCD cameras and their associated filter wheels.

The field of view through the TV-60is is narrow compared to conventional telephoto lenses. Piggyback astrophotographers may find it a challenge to locate a dim target. Instead, attach the Tele Vue Qwik Point finder to the lens shade or use an auxiliary finder centered on the camera's field of view.

For 35mm photography, the TV-60is produces a 5.7° by 3.8° field of view. Popular digital SLR cameras like the Canon 350D and 20Da use imaging sensors smaller than 35mm film and, thus, introduce a 1.6x "crop factor" resulting in a 3.6° by 2.4° field of view, or about half that of 7x50 binoculars.

A digital SLR's field of view can be changed from "landscape" to "portrait" without dismounting the lens assembly from the TV-60is. The camera is coupled to the field flattener, which, in turn, is locked in place with two setscrews. Loosening these screws allows you to rotate a camera 90°. Rotating the field-flattener threads moves the focus point, making it necessary to refocus the camera after rotating it.

I have one caution about, but not a criticism of, the TV-60is: The aluminum structure is temperature sensitive and will alter focus if the temperature changes significantly. Over the course of a night, I noted a .005-inch focus change as the temperature dropped 20° Fahrenheit. Refocus before each exposure to obtain the sharpest results.

Under dark skies, the TV-60is displays no vignetting, which causes an image's corners to appear dark. Unfiltered images show a slight central hot spot when under bright urban skies.

The lens cap snaps into 77mm threads on the front of the retractable lens hood. It is tempting to think of this as the place to put any filter used with the TV-60is, but placing a filter at the front of the lens hood negates the purpose of having the hood. Instead, removing the field flattener reveals 48mm threads on the forward end of the field flattener. The internal 48mm threads allow the use of smaller, less expensive filters and protects delicate filters from inclement weather.

The best of both worlds

The TV-60is is designed as a photographic system, but it can also be converted into a visual telescope by unthreading the field flattener and inserting a 2" diagonal. Tele Vue supplies a diagonal bushing, which threads into the rear of the tube to prevent diagonal side play. Using this configuration, the TV-60is is capable of 1.9" resolution.

Useful visual powers range between 6.5x and 180x. A 7.3° field of view is possible using a 55mm eyepiece. The TV-60is will visually focus as close as 10 feet. My wife, Mary, has discovered the daytime versatility of the scope for bird-watching.

CYGNUS' BUTTERFLY NEBULA (IC 1318, center) appears as red clouds amid a sea of stars. The bright star is Cygnus' central star, Sadr (Gamma [γ] Cygni).

/// SPECIFICATIONS

TELE VUE TV-60is

Type: 2-element apochromatic refractor
Lens diameter: 2.4 inches (60 millimeters)
Focal length: 360mm
Focal ratio: f/6
Length: 11.5 inches with field flattener
Weight: Approx. 7 pounds
Visual resolution: 1.9"
Photographic resolution: 240 line pairs per mm
Visual magnification: 6.5x to 180x
Close focus: Approx. 10 feet
Max. visual field: 7.3° (using a Tele Vue 55mm Plössl eyepiece)
35mm film photographic field: 3.8° by 5.7°
Photographic image scale: 4° per inch
Street price: $1,695
Digital-focusing micrometer: $390

Contact information:
Tele Vue Optics, Inc.
32 Elkay Drive
Chester, NY 10918
[t] 845.469.4551
[w] www.TeleVue.com

TELE VUE'S 2" focuser is threaded inside to allow for easy installation of filters like the infrared-blocking filter shown.

The bottom line

Tele Vue's TV-60is is the sharpest affordable astrophotography system I have used. The telescope's outstanding optical quality, solid mounting cradle, beefy focuser, and digital-focusing scale combine to provide high-resolution performance with the ease of using piggyback astrophotography techniques.

I recommend the Tele Vue TV-60is to anyone who wishes to take their astrophotography to a higher level of performance and enjoyment.

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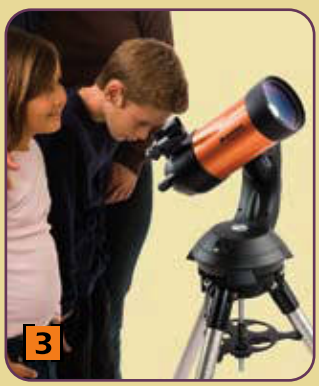

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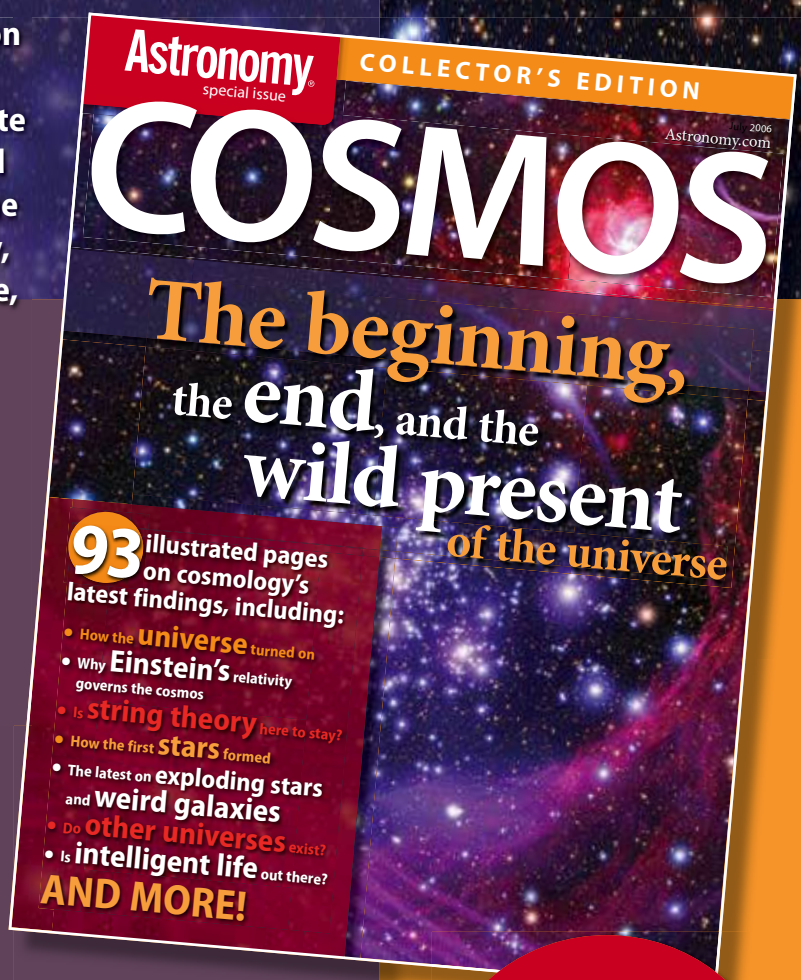
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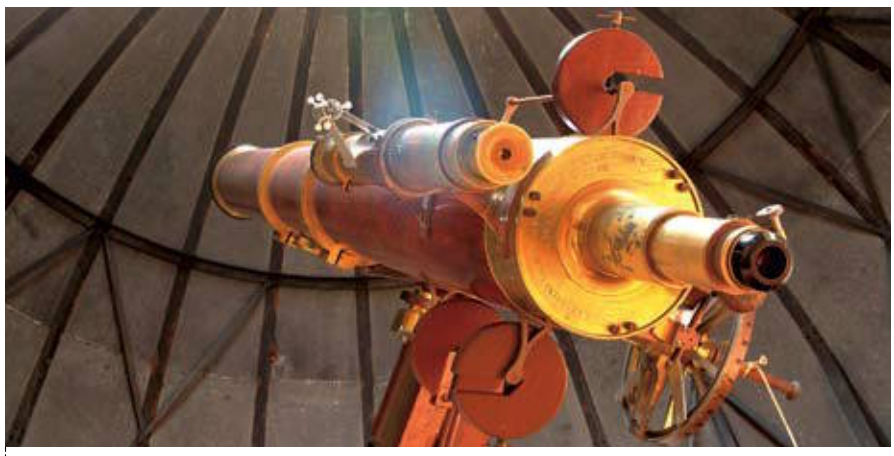
ScopeOut brings the past to the present

Held at the Cincinnati Observatory

Center, ScopeOut is a daylong event that should interest those with a taste for astronomical history. The observatory possesses restored Riefler pendulum clocks, an 1843 Merz and Mahler refractor, and a 1904 Alvan Clark refractor.



MARY STRUBBE

THIS ALVAN CLARK REFRACTOR is a major attraction for ScopeOut attendees. After darkness falls, skygazers will be able to take a peek through this classic instrument.

The public will be treated to lectures, workshops, door prizes, and a raffle. The keynote speaker is Sten Oswald, who studies the Sun and its relationship with Earth.

For more information, visit www.cincinnatiobservatory.org.

SEPTEMBER 15–16
Westcliffe Star Party
Cross D Bar Trout Ranch, Westcliffe, Colorado. This star party will be held on a working ranch. For more information, visit www.rmastronomy.info.

SEPTEMBER 16–18
Astronomical Society of the Pacific Annual Meeting
Baltimore Hyatt Regency, Baltimore. This conference will bring together journalists, educators, and scientists working in astronomy and education to discuss ideas concerning public outreach. For more information, visit www.astrosociety.org.

SEPTEMBER 16
Digital Astrophotography Workshop
Kitt Peak National Observatory, Tohono O'Odham Reservation, Arizona. Imaging expert Robert Reeves will show how to get the best results with digital cameras, and introduce photo-processing techniques. For more information, visit www.noao.edu/outreach/kpvc/imaging.html.

SEPTEMBER 16–24
Okie-Tex Star Party
Camp Billy Joe, near Kenton, Oklahoma.

Although this event will feature vendor exhibits, door prizes, and workshops, the real draw is the dark-sky observing. For more information, visit www.okie-tex.com.

SEPTEMBER 20–23
Enchanted Skies Star Party
Socorro County Pound Ranch, Socorro, New Mexico. This star party will offer observing, lectures, and workshops. *Astronomy* Associate Editor Laura Layton will attend. For more information, visit www.socorro-nm.com/starparty.

SEPTEMBER 21–24
Alberta Star Party
Eccles Ranch Observatory, Caroline, Alberta. This is a no-frills campsite; visitors must supply their own water and electricity. For more information, visit calgary.rasc.ca/asp2006.htm.

SEPTEMBER 21–24
Astrofest
Vana's Farm, near Kankakee, Illinois. Sponsored by the Chicago Astronomical Society, this event will include observing, lectures, and vendor exhibits. *Astronomy* Senior Editor Michael E. Bakich will attend. For more information, visit www.chicagoastro.org.

SEPTEMBER 21–24
CalStar
Lake San Antonio County Park, Paso Robles, California. This star party will offer activities for observers of all experience levels. For more information, visit www.sjaa.net/calstar.

SEPTEMBER 21–24
Iowa Star Party
Garst Farm Resort, Coon Rapids, Iowa. Accommodations range from tents to suites in a bed-and-breakfast. For more information, call Liz at 712.684.2964; web site, www.iowastarparty.com.

SEPTEMBER 22–23
Cathedral Gorge Star Party
Cathedral Gorge State Park, near Panaca, Nevada. This site is one of Nevada's finest state parks and has special areas developed specifically for stargazing. For more information, visit www.lvastronomy.com.

SEPTEMBER 22–24
Connecticut Star Party
Hartford County 4H Camp in Marlborough, Connecticut. This star party will feature lectures on topics from light pollution to robotic science missions. For more information, visit www.asnh.org/spec_events/csp/csp.html.

SEPTEMBER 22–24
Great Lakes Star Gaze
River Valley RV Park, near Gladwin, Michigan. This site provides a dark sky without driving to a rural location in northern Michigan. For more information, visit www.boonhill.net/sunset.

SEPTEMBER 22–24
South Jersey Star Party
Belleplain State Forest, near Woodbine, New Jersey. This star party will provide great observing at the close of warm-weather season. For more information, visit hometown.aol.com/sjastroc.

SEPTEMBER 26–OCTOBER 1
Northern Prairie Starfest
Black Nugget Lake Campground, Tofield, Alberta. Activities will include observing, canoeing, and fishing. The site is located on a migration flyway, providing exceptional birding. For more information, visit edmontonrasc.com/nps.html.

SEPTEMBER 30
Virginia Association of Astronomy Societies Convention
Randolph-Macon College, Ashland, Virginia. This event will feature door prizes, speakers, displays, and vendors. For more information, visit www.richastro.org. A

CONTACT INFORMATION
Please submit club announcements 5 months in advance to Coming Events, *Astronomy*, P. O. Box 1612, Waukesha, WI 53187, or jmcgovern@astronomy.com. Also use this e-mail address to submit your events for our online calendar.

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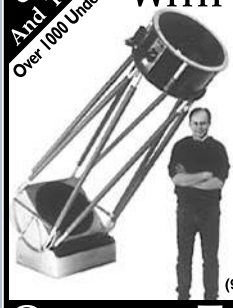

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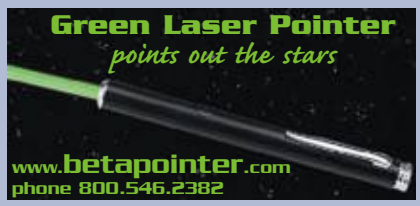

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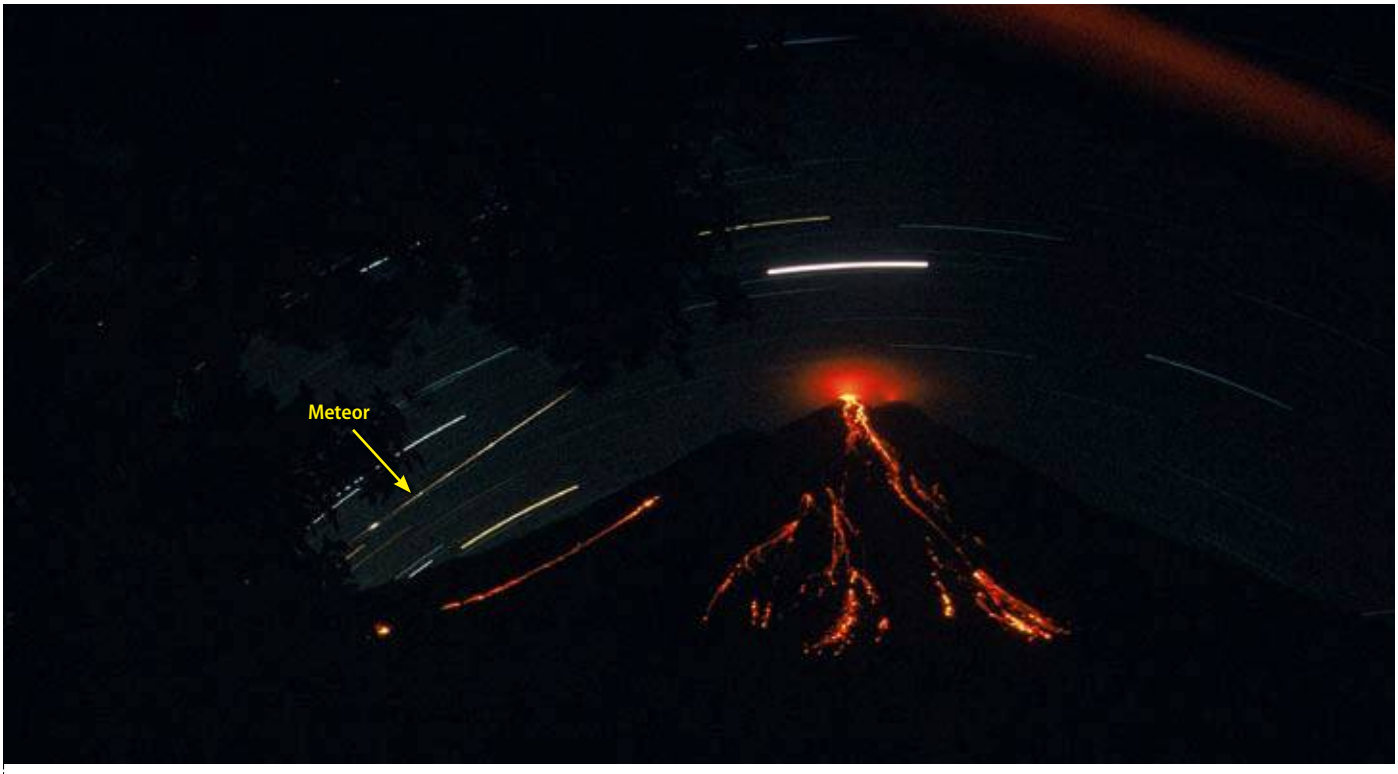
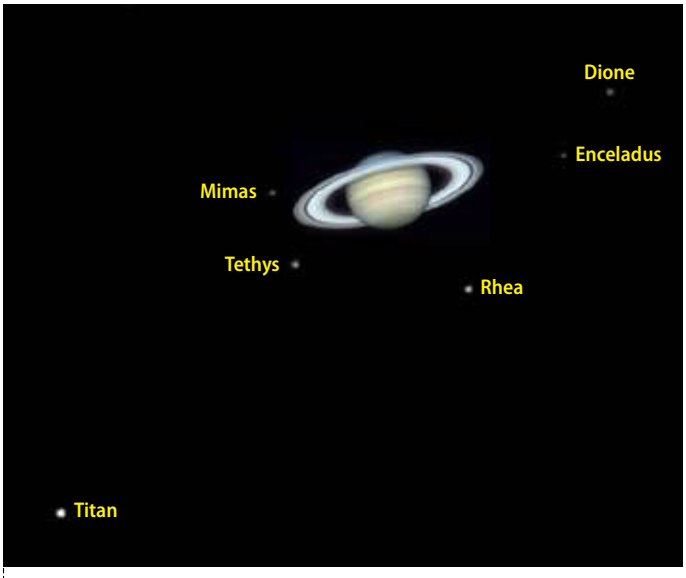
Many amateur astronomers consider NGC 1300 in Eridanus the River the finest barred spiral galaxy. It lies more than 70 million light-years away and spans 100,000 light-years. NGC 1300 glows at magnitude 10.4 and measures 6.2' by 4.1'. Find this galaxy 1° north of Tau^4 (τ^4) Eridani. In addition to nearly 9 hours of exposures, the imager spent more than 90 hours processing the image with techniques he developed. The result: more visible faint detail, especially in the spiral arms. Note the many small, faint galaxies in this region. Most lie 5 times as far away as NGC 1300.

▲ **NGC 1300** (20-inch RC Optical Systems Ritchey-Chrétien reflector at f/8, SBIG STL-11000XM CCD camera, LRGB image with exposures of 255, 90, 54, and 108 minutes, respectively) /// **R. JAY GABANY, SAN JOSE, CALIFORNIA**

► **THE MOON** is a difficult subject for astroimagers because of the low contrast among its surface features. This 42-image mosaic captures the full face in great detail. (9.25-inch Celestron Schmidt-Cassegrain telescope at f/10, ToUcam Pro webcam; for each of the 42 images, the imager selected and stacked the best 20 to 30 frames out of 500, taken September 6, 2005) /// **TORSTEN EDELMANN, LANDSBERG, GERMANY**



STAR TRAILS and a meteor cross above Arenal Volcano in Costa Rica November 13, 2004. The bright star trail belongs to Canopus (Alpha [α] Carinae). Star-trail photography is easy, but you have to be careful not to overexpose the foreground. (Honeywell Pentax camera, 80mm lens at f/4.5, Agfa RSX-II film, ISO 50, 45-minute tripod-mounted exposure) /// **AMELIA GOLDBERG, HOUSTON**



YOU CAN CAPTURE several of Saturn's moons through a telescope. Here, Titan shines brightest at magnitude 8.1. Rhea is next brightest, at magnitude 9.4. Then come Tethys (9.9), Dione (10.1), Enceladus (11.4), and Mimas (12.6). (Planet: 14-inch Celestron Schmidt-Cassegrain telescope at f/36; moons shot at f/10; ToUcam webcam, taken January 26, 2006, at 22h11m UT) /// **JAMIE COOPER, WOOTTON, ENGLAND**

OPEN CLUSTER M7 in Scorpius lies in the direction of the Milky Way's center. At magnitude 3.3, the cluster stands out well visually, especially through binoculars. Long-exposure images, however, reveal the richness of the background star field. (6-inch Takahashi FCT 150 at f/5, SBIG STL-11000XM CCD camera, Astrodon filters, LRGB image with exposures of 60, 30, 30, and 30 minutes, respectively) /// **FILIPPO CIFERRI, ROME**

Send your photos to: *ASTRONOMY* Reader gallery, P. O. Box 1612, Waukesha, WI 53187; e-mail to readergallery@astronomy.com.
Please include your full name, date and location of image, and complete photo data: telescope, camera, film, and exposure information.

GLOBULAR CLUSTER M75 in Sagittarius is a compact, magnitude 8.5 object that spans 7'. This cluster lies 67,500 light-years away. (20-inch RC Optical Systems Ritchey-Chrétien reflector at f/5.5, SBIG ST-10XME CCD camera, LRGB image with exposures of 15, 5, 5, and 5 minutes, respectively) /// **KEN SIARKIEWICZ/ADAM BLOCK/NOAO/AURA/NSF, KITT PEAK NATIONAL OBSERVATORY (ARIZONA)**

THE SUN is dangerous to look at. At sunrise or sunset, however, it sits on the horizon, so the radiation reaching your eyes is greatly diminished. These are the times to capture a quick image. (Olympus Camedia C750 UZ digital camera, 10x optical zoom lens at f/3.7, ISO 50, 1/500-second exposure taken July 21, 2004, at 21h00m UT, from the city walls of St. Malo, France)
/// **THOMAS KINSELLA, DUBLIN, IRELAND**

NGC 1931 is an open star cluster embedded in nebulosity that sits less than 1° east of Phi (ϕ) Aurigae and 1° west of a much brighter open cluster, M36. NGC 1931 shines faintly at magnitude 10.1 and measures 3' across. (14.5-inch RC Optical Systems Ritchey-Chrétien telescope at f/9, SBIG ST-10XME CCD camera, Astrodon filters, LRGB image with exposures of 60, 30, 30, and 30 minutes, respectively) /// **RANDY BREWER, BAYTOWN, TEXAS**

SHARPLESS 2–216 — the second-closest planetary nebula to Earth — glows so faintly that the imager needed 11 hours total exposure time to capture it in mapped color. Combined images through a Hydrogen-alpha filter acted as red, an image through an Oxygen III filter substituted for green, and blue was mimicked by an image taken through a Helium II filter. (Nikon 300 ED lens at f/2.8, SBIG ST-8XME CCD camera, Hα/OIII/HeII image, with exposures of 8 hours [96 five-minute exposures], 2 hours, and 1 hour, respectively) /// **DEAN SALMAN, TUCSON, ARIZONA**

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